NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3642

EFFECT OF SHALLOW WATER ON THE HYDRODYNAMIC CHARACTERISTICS OF A FLAT-BOTTOM PLANING SURFACE

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SUMMARY

An experimental investigation was made on the Langley tank no. 2 monorail to determine the effect of shallow water on the hydrodynamic characteristics of a flat-bottom planing surface. Measurements were taken of lift, drag, and trimming moment at a constant speed over a range of trims, wetted lengths, and clearances between the model and a false bottom in the tank.

The values of lift, drag, and trimming moment about the trailing edge of the model all increased with decreasing clearance. The most apparent increases occurred as clearance decreased below 2.5 inches (1 beam). With combinations of high wetted length and high trim, however, the values began to increase at somewhat greater clearances. The lift-drag ratio increased with decreasing clearance for wetted lengths greater than 0.8 beam and trims less than 16°. The roach in the wake of the model increased in height and moved farther aft of the model as the clearance decreased.

A description of the monorail and its associated apparatus is included in an appendix.

INTRODUCTION

The effects of shallow water on the forces acting on a planing body would be expected to be similar to ground effects on wing forces. The magnitudes of the effects in the planing case, however, have not been established very closely, and become of particular interest in the operation of water-based aircraft off ramps or beaches where the water depth approaches zero.

A preliminary investigation was therefore made on the Langley tank no. 2 monorail to determine variations of the lift, drag, and trimming moment of a flat planing surface during pure planing in shallow water of various depths. The experiments were made on water that was made shallow by means of adjustable false bottoms in the test region. Sufficient ranges of trim and wetted lengths were included for evaluation of the importance of the proximity of the bottom for typical hydro-ski take-off and landing conditions.

SYMBOLS

C_D	drag coefficient based on wetted area, $\frac{\text{Drag}}{qS}$
C_L	lift coefficient based on wetted area, $\frac{\text{Lift}}{qS}$
$C_{M_{te}}$	trimming-moment coefficient about trailing edge of model, $\frac{\text{Moment}}{qSl_m}$
C_V	speed coefficient, $\frac{V}{\sqrt{gb}}$
b	beam, 0.208 ft
g	acceleration due to gravity, 32.15 ft/sec^2
l_m	mean wetted length, ft
q	dynamic pressure, $\frac{1}{2}\rho V^2$ lb/sq ft
S	wetted area, $l_m b$, sq ft
V	speed, ft/sec
z	clearance (vertical distance between trailing edge of model and false bottom of tank), ft
ρ	mass density, 1.977 slugs/cu ft for salt-water data, 1.938 slugs/cu ft for fresh-water data
τ	trim angle, deg

MODEL AND APPARATUS

The investigation was made at the Langley tank no. 2 monorail. A description of the monorail and its carriages and instrumentation is given in the appendix. A drawing of the model used is presented in figure 1. This model, which was of solid mahogany, was 19.6 inches long and 2.5 inches wide. It had a flat bottom surface and a longitudinally curved, circular-arc top surface.

The model was attached to a three-component strain-gage balance by means of two struts and a crossbar, as shown in the test setup illustrated in figure 2. The balance was housed in a metal box to protect it from spray. Adjustment in vertical position was provided by moving the staff vertically. Adjustment in trim was provided by a pivot in the balance.

Four steel tables, each 10 feet long and 6 feet wide, were placed end to end in the tank to form a false bottom. A given depth of water was obtained by adjusting the height of each table with four brass screws operated by hand cranks through a slot in the table top. A sketch of the test setup showing the tables is given in figure 3.

The table tops were made of 1/8-inch sheet steel bolted to an angle-iron framework. The maximum variation from a horizontal plane was approximately 0.04 inch along the longitudinal center line of each table. The gaps between adjacent tables were kept to about 1/2 inch or less and no effects of the gaps were discernible on the forces recorded.

For the determination of wetted lengths, underwater photographs of the grid inscribed on the bottom of the model were taken by means of an electrically operated camera housed in a watertight box mounted under the last table along the run. The photographs were taken through a glass plate in the table top. The camera shutter, high-speed flash lamps, and film advance were actuated by a photoelectric unit when a light beam was interrupted by the carriage as the model passed over the camera.

All the shallow-water runs were made in salt water. The difference in density noted in the list of symbols was caused by the fact that the tank had been drained and refilled with fresh water when the deepwater runs were made.

The estimated accuracies of the test measurements are as follows:

Trim angle, deg	±0.1
Speed, ft/sec	±0.05
Lift, lb	±0.25
Drag, lb	±0.1
Trimming moment, ft-lb	±0.25
Wetted length, in.	±0.05

PROCEDURE

All the runs were made at a nominal speed of 25 feet per second ($C_V = 9.66$). This speed was chosen to avoid the effects of buoyancy as much as possible without exceeding the force limits on the balance.

The model was tested at initial trims of 4°, 8°, 12°, 16°, and 20° and at wetted lengths of 1 to 16 inches ($l_m/b = 0.4$ to 6.4). Each condition was investigated at clearances of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, and 4.0 inches ($z/b = 0.2$ to 1.6) and a separate set of runs was made in deep water (72 inches).

The test results were corrected for force tares due to windage. The tares on the model and struts were determined by making runs with the model just clear of the water at each trim value tested. Strut tares were determined from runs made with the model removed. The tares on the model alone were considered as the differences between the two sets of tares obtained. For a given trim and wetted length, the tare on the model was determined by multiplying the total tare for the model at that trim by the ratio of the unwetted length to the total length of the model. The strut tare was added to this value in correcting the test results.

Measurements of lift, drag, and trimming moment were recorded. The trimming moment was measured about the pivot of the balance, and the trimming moment about the trailing edge of the model was calculated from these data and the configuration of the system. Trimming-moment coefficients were based on wetted area and wetted length. Lift and drag were reduced to coefficients based on wetted area. The measured speeds were used in determining all coefficients.

Wetted lengths were read from underwater photographs. The wetted length l_m was measured from the trailing edge of the model to the intersection of the heavy spray line with the planing bottom. As can be seen in figure 4, the heavy spray line was slightly curved and the wetted length at the center line of the model was approximately 0.2 inch greater than at the chine. The arithmetic mean of the chine and center-line wetted lengths was used for the value of l_m.

Trim values were found to vary with moment about the pivot of the strain-gage balance because of deflections in the balance; the initial values of trim were corrected for this variation. The variation in trim caused the clearance values to be greater than those initially set. As a result of the testing procedure followed (in order to reduce the number of table settings), nonintegral values of wetted length were obtained. Cross plots therefore were made in order to obtain integral values of trim and wetted length. The data, which were reduced to coefficient form to minimize effects of speed variations, were plotted against wetted length at constant clearance with initial trim as a parameter, and the corrected trim values were noted for each point. From the faired curves of these plots a cross plot was made against trim at constant clearance with integral values of wetted length as a parameter. The final plots were then made against corrected values of clearance with even values of trim and wetted length.

Still and motion pictures were taken to show the effect of clearance on the flow patterns produced by the model.

RESULTS AND DISCUSSION

The data obtained from the tests are given in coefficient form in table I and the results are plotted in figures 5 to 8. The points shown on the curves are from the cross plots made in order to obtain the data in terms of integral values of trim and wetted length.

Deepwater data, which were obtained for comparison purposes, are presented in figure 5. The lift values are slightly lower than values previously obtained with a similar model. These lower values probably result from the fact that the nominally sharp chines of the wooden model were actually slightly rounded. Unpublished data obtained from tests in Langley tank no. 2 indicate that even slight rounding of the chines reduces the lift forces produced by a flat-bottom planing surface.

The effect of clearance on lift coefficient is shown in figure 6. As can be seen, the lift coefficient increases with decreasing clearance. The most apparent increases in the lift coefficient occurred as clearance values decreased below 2.5 inches (1 beam). However, with a combination of high wetted length and high trim the lift coefficients continued to decrease as the clearance increased to values greater than 2.5 inches and, as indicated in figures 6(e) and 6(f), would probably reach the deepwater value at a clearance greater than 4 inches.

As shown in figures 7 and 8, drag and trimming-moment coefficients increased with decreasing clearance in the same manner as did the lift coefficients; that is, most of the variation of drag and trimming-moment coefficient occurred as clearance decreased below 2.5 inches (1 beam). The percentage increase in drag coefficient over the deepwater value was, however, slightly less than the percentage increase in lift coefficient because the friction drag is unaffected by an increase in lift, and only the drag due to lift ($C_L \tan \tau$) increases in proportion to an increase in lift.

The effect of clearance on lift-drag ratio is shown in figure 9. At a wetted length of 2 inches ($l_m/b = 0.8$), no variation with clearance was noted throughout the trim range tested. For larger wetted lengths, a variation with clearance was noted only for trims less than 16°. At larger trim values, the friction drag becomes a smaller part of the total drag and for this reason the variation of lift-drag ratio with clearance at the larger trim values is negligible. The variation of lift-drag ratio with clearance increased with increasing wetted length. No difference was noted between the lift-drag ratios for clearances of 4 inches and 72 inches.

The variation of maximum lift-drag ratio with clearance and wetted length is shown in figure 10. Figure 10(a) gives the variation with clearance for various wetted lengths and shows that the increase in maximum lift-drag ratio with decreasing clearance becomes more apparent at larger values of wetted length. The values vary little with clearance at a clearance larger than about 3 inches (1.2 beams). Figure 10(b), which is a cross plot of figure 10(a), shows the variation with wetted length for various clearance values.

In figure 11 is shown the change in appearance of the roach as the model approaches and progresses over the edge of the tables. When in deep water the roach was low and not easily distinguishable (fig. 11(a)). In shallow water, the roach became more pronounced, rising higher above the free water surface and moving farther aft of the model. At a clearance of 0.5 inch (0.2 beam), the roach was quite pronounced (figs. 11(b) and 11(c)).

As can be seen in figure 11, the roach changed abruptly at the edge of the tables. Similarly, the forces on the model increased abruptly with the abrupt decrease in clearance as the model passed over the edge of the submerged tables.

CONCLUSIONS

The results of tank tests of a flat-bottom planing surface with varying clearances between the trailing edge of the planing surface and a false bottom in the tank may be summarized as follows:

1. Lift, drag, and trimming moment about the trailing edge all increased with decreasing clearance.

2. The most apparent increases occurred as clearance decreased below 2.5 inches (1 beam). With a combination of high trim and high wetted length, however, the values began to increase at somewhat greater clearances.

3. The lift-drag ratio increased with decreasing clearance for wetted lengths greater than 0.8 beam and trims less than 16°.

4. The roach produced by the model increased in height and moved farther aft of the model as clearance decreased.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., January 19, 1956.

APPENDIX

DESCRIPTION OF THE LANGLEY TANK NO. 2 MONORAIL AND ITS OPERATION

An additional test facility at the Langley tank no. 2 is a 180-foot monorail that has been installed at the north end of the tank beyond the point where the main-carriage runs usually end. The monorail, which consists of 2.25-inch by 5.75-inch channel beams fastened end to end, is supported about 3 feet above the 6-foot water level by steel brackets attached to the beach on the west side of the tank. A schematic sketch of the monorail system is shown in figure 12. Figure 13 is a photograph showing a general view of the monorail from the opposite direction.

The monorail forms a track for two lightweight cable-driven carriages, one used for towing dynamic models and the other used for the free launching of models to investigate landing behavior of seaplanes and ditching characteristics of land planes. Both carriages are towed by a 1/8-inch steel cable driven by an electric motor. Copper conducting bars installed in the channel of the monorail provide power to the dynamic-model towing carriage through brush contacts for the operation of lights, cameras, and other auxiliary equipment that may be installed on the carriage.

The dynamic-model towing carriage runs from south to north. A photograph of this carriage is shown in figure 14. The length of run from the starting point to the point where the carriage is released from the towing cable is approximately 120 feet. The carriage is attached to the towing cable by a clamp which is automatically released at the end of the run. The carriage then coasts into a shock cord which acts as an arresting gear. In order to eliminate rebound from the arresting gear, hooks are provided on the side of the carriage which ratchet along a chain positioned a short distance beyond the cable release. As the carriage slows down and tends to rebound from the shock cord, the hooks engage the chain, which is held fixed by a mechanical brake. The model may then be raised out of the water before the brake is partially released to allow the force of the shock cord to drive the carriage and chain back to the point at which the shock cord was first encountered.

The launching carriage, shown in figure 15, runs from north to south and is used to accelerate a model to a desired landing speed. This speed is maintained until the carriage reaches the launching point, where it is rapidly decelerated by a shock-cord arrangement similar to that used for the dynamic-model towing carriage and the model is catapulted forward to glide freely onto the water. Models may be launched at various attitudes, and yaw and roll may be incorporated if they are desired. The aerodynamic control surfaces are set to maintain the desired attitude, yaw, and roll until contact with the water is made.

The recoil mechanism for the launching carriage is similar to that for the dynamic-model carriage but, because of the higher speeds and much more abrupt stops, much greater forces must be absorbed. For this reason, the chain is not held by a mechanical brake but instead is connected to an oil damper that allows the carriage to return slowly to relieve the tension in the shock cord. The carriage is then manually disengaged from the chain.

The maximum speed for the dynamic-model carriage is 30 feet per second whereas for the launching carriage it is 100 feet per second. These speeds are limited by the braking mechanisms and the accelerating and stopping distance required in each case.

The speed and acceleration are controlled through the use of electron tubes (thyratrons) supplying current to the armature of the drive motor. A reference voltage corresponding to the desired speed is set up to oppose a voltage produced by a tachometer generator connected to the drive motor. The drive motor is then started by activating the thyratrons and the motor increases in speed until the reference voltage is canceled by the tachometer generator voltage, at which point the thyratrons cut out. The speed is then automatically maintained by the firing of the thyratrons whenever the tachometer voltage is lower than the reference voltage. The rate of acceleration is controlled by limiting the current output of the thyratrons on the initial climb to the reference voltage.

Models are attached to the dynamic-model towing carriage through a rectangular staff operating in a roller cage on the carriage. The model may be operated either fixed or free in trim and/or rise and these quantities may be measured by means of electric slide wires. Lift and drag forces on the model and pitching moment about a fixed point above the model are measured by the use of a three-component electric strain-gage balance.

The outputs from the slide wires and strain gages are transmitted by means of a 14-component shielded cable to strip-chart pen recorders located on shore on the east side of the tank. (See fig. 16.) The cable is fed out and taken in through a pulley system located on shore at a position abeam of the carriage at the midpoint of its run. The pulley system consists of a block and tackle with one end fixed and the other fastened to a shock cord. The shock cord maintains tension in the cable so that it is reeled in when the direction of the carriage movement is such as to produce slack. Inasmuch as the cable extends up to 80 feet in either direction from the central location, the cable must be kept under tension to prevent its dipping into the water.

Two methods are used for measuring the speed of the towing carriage. One method makes use of Micarta blocks imbedded at 5-foot intervals over the last 40 feet of the run in one of the copper conducting bars mounted in the monorail channel. An electric circuit is established from the speed recorder to the bar, then through a brush to the carriage frame, and through the metal wheels of the carriage to the monorail, which acts as a ground. As the carriage brush passes over a Micarta block, the circuit is interrupted and an impulse of current burns a mark on a strip of electrically sensitive paper attached to a constant-speed rotating drum on the speed recorder. Because the speed of the rotating drum and the distance between the blocks are known, the speed of the carriage over the range covered by the Micarta blocks may be calculated.

In order to obtain a continuous record of the carriage speed during the entire run, a second method is used. The output of a tachometer generator driven by a wheel resting on the towing cable is fed to one of the strip-chart recorders. This method is calibrated by comparison with the Micarta block method.

The speed of the launching carriage is measured by a method similar to the Micarta block method. In this case, the carriage breaks two small wires spaced a fixed distance apart and thus causes a recording mechanism to burn two marks on a piece of electrically sensitive paper mounted on a drum revolving at a constant speed. The carriage speed is measured during the time interval between its release from the towing cable and its contact with the arresting gear.

TABLE I.- DATA MEASURED FOR FLAT-BOTTOM PLANING SURFACE

(a) Shallow-water data

[ρ = 1.977 slugs/cu ft]

$\frac{z}{b}$	τ, deg	$\frac{l_m}{b}$	C_V	C_L	C_D	$C_{M_{te}}$
0.216	3.8	6.73	9.76	0.029	0.0073	0.0179
.216	3.8	5.45	9.60	.032	.0072	.0238
.216	3.8	3.29	9.78	.042	.0090	.0331
.216	3.8	2.49	9.70	.051	.0101	.0423
.216	3.8	1.49	9.70	.068	.0117	.0684
.216	3.8	1.01	9.76	.090	.0102	.0741
.208	3.9	.69	9.68	.104	.0135	.1192
.220	7.7	6.69	9.70	.080	.0175	------
.228	7.6	4.85	9.62	.093	.0177	.0594
.228	7.6	5.31	9.91	.088	.0178	.0549
.228	7.6	4.89	9.74	.093	.0181	.0594
.228	7.6	3.61	9.70	.102	.0186	.0675
.232	7.5	2.69	9.66	.122	.0205	.0859
.228	7.6	1.73	9.66	.149	.0261	.1189
.228	7.6	1.05	9.78	.181	.0309	.1577
.228	7.6	1.09	9.76	.175	.0289	.1557
.220	7.7	.85	9.70	.195	.0323	.1829
.212	7.8	.49	9.74	.245	.0369	.2478
.232	11.4	5.17	9.74	.136	.0324	.0796
.232	11.4	5.17	9.70	.140	.0329	.0820
.232	11.4	5.05	9.68	.139	.0327	.0832
.232	11.4	5.29	9.66	.134	.0323	.0785
.228	11.5	6.69	9.66	.133	.0326	.0763
.240	11.3	3.45	9.78	.166	.0396	.1077
.240	11.3	3.49	9.76	.164	.0394	.1077
.240	11.3	2.69	9.76	.172	.0371	.1130
.240	11.3	1.81	9.68	.225	.0493	.1610
.232	11.4	1.29	9.76	.243	.0530	.1880
.228	11.5	.89	9.70	.279	.0600	.2220
.224	11.6	.57	9.78	.304	.0654	.2550
.240	15.1	5.25	9.60	-----	.0613	------
.232	15.3	6.73	9.89	-----	.0600	------
.248	15.0	3.65	9.66	.229	.0693	.1491
.248	15.0	2.69	9.66	.248	.0735	.1566
.240	15.1	2.01	9.78	.280	.0787	.1954
.236	15.2	1.53	9.60	.308	.0854	.2158
.232	15.3	1.05	9.66	.342	.0960	.2582
.224	15.5	.53	9.72	.431	.1207	.3914
.252	18.7	3.69	9.91	.274	------	------
.252	18.7	3.65	9.78	.276	.1001	.1775
.252	18.7	2.81	9.58	.324	.1210	.2310
.244	18.9	1.89	9.58	.346	.1238	.2466
.240	19.0	1.57	9.74	.368	.1299	.2672
.232	19.2	1.09	9.60	.407	.1449	.3045
.220	19.5	.57	9.74	.450	.1564	.3425
.408	3.9	6.65	9.20	.023	.0067	.0107
.408	3.9	6.65	9.58	.024	.0070	.0167
.408	3.9	4.69	9.70	.028	.0069	.0214
.408	3.9	6.25	9.70	.029	.0075	.0190
.408	3.9	2.69	9.70	.036	.0074	.0306
.408	3.9	1.81	9.68	.045	.0076	.0420
.408	3.9	1.25	9.66	.059	.0105	.0622
.408	3.9	6.85	9.64	.023	.0072	.0167
.412	7.8	6.69	9.28	.071	.0170	.0465
.412	7.8	6.69	9.58	.070	.0144	.0441
.412	7.8	6.65	9.66	.072	.0143	.0440
.420	7.7	5.01	9.76	.074	.0158	.0499
.420	7.7	3.57	9.66	.083	.0169	.0603
.428	7.6	3.49	10.28	.087	.0166	.0627
.428	7.6	3.41	10.28	.086	.0171	.0650
.428	7.6	3.57	9.93	.086	.0156	.0603
.420	7.7	2.77	9.64	.090	.0165	.0672
.420	7.7	1.65	9.60	.118	.0185	.0885

$\frac{z}{b}$	τ, deg	$\frac{l_m}{b}$	C_V	C_L	C_D	$C_{M_{te}}$
0.420	7.7	1.29	9.91	0.135	0.0228	0.0106
.420	7.7	1.29	9.49	.131	.0207	.0957
.412	7.8	1.01	9.74	-----	------	------
.412	7.8	.53	9.74	.184	.0313	.1750
.428	7.6	3.49	9.82	.082	.0154	.0580
.428	7.6	3.49	9.66	.086	.0152	.0592
.428	11.5	5.41	9.70	.123	.0308	.0785
.428	11.5	5.37	9.78	.124	.0318	.0797
.424	11.6	7.53	9.68	-----	.0328	------
.432	11.4	3.41	9.57	-----	.0382	------
.432	11.4	3.49	9.58	.145	.0365	.1006
.432	11.4	2.69	9.76	.154	.0408	.1158
.432	11.4	2.57	9.74	.156	.0389	.1118
.432	11.4	1.89	10.26	.182	.0420	.1379
.432	11.4	1.89	9.91	.183	.0401	.1227
.428	11.5	1.49	9.70	.200	.0450	.1530
.424	11.6	1.09	9.49	.217	.0437	.1317
.428	11.5	1.09	9.78	.217	.0462	.1500
.416	11.7	.61	9.68	.264	.0543	.1873
.436	15.2	3.53	9.74	.196	.0576	.1278
.436	15.2	5.97	9.70	-----	.0589	------
.436	15.2	2.81	9.78	.218	.0670	.1544
.436	15.2	2.05	9.70	.241	.0694	.1733
.436	15.2	1.97	10.03	.246	.0692	.1767
.436	15.2	2.17	9.64	.230	.0671	.1618
.432	15.3	1.53	9.80	.277	.0790	.2182
.428	15.4	1.09	9.78	.292	.0810	.2061
.420	15.6	.57	9.76	.367	.0984	.2375
.420	15.6	.53	9.78	.350	.0890	.1576
.444	18.9	2.77	9.66	-----	------	------
.444	18.9	2.77	9.68	.266	.0953	.1720
.444	18.9	3.73	9.66	.252	.0911	.1646
.444	18.9	3.65	9.70	.255	.0903	.1633
.440	19.0	2.17	9.64	.303	.1116	.2228
.436	19.1	1.57	9.93	.326	.1151	.2335
.432	19.2	1.17	9.68	.350	.1255	.2699
.420	19.5	.65	9.66	.414	.1416	.3079
.420	19.5	.69	9.60	.400	.1371	.2795
.608	3.9	4.73	9.62	.024	.0074	.0202
.608	3.9	1.81	9.76	.050	.0113	.0700
.608	3.9	2.49	9.16	.033	.0057	.0270
.608	3.9	2.53	9.68	.032	.0056	.0235
.608	3.9	1.57	9.80	.045	.0058	.0372
.608	3.9	1.05	9.80	.056	.0052	.0354
.608	3.9	.49	9.91	.089	.0044	.0162
.608	3.9	.49	9.99	.088	.0079	.0323
.620	7.7	5.01	9.66	.066	.0132	.4514
.620	7.7	5.09	9.66	.065	.0130	.0440
.608	7.9	6.77	9.70	.062	.0131	.0405
.620	7.7	3.57	9.66	.076	.0161	.0568
.620	7.7	2.37	9.58	.089	.0171	.0670
.620	7.7	1.97	9.72	.100	.0178	.0796
.620	7.7	1.25	9.87	.124	.0189	.0945
.620	7.7	.97	9.99	.135	.0202	.0990
.612	7.8	.93	9.68	.137	.0200	.0942
.612	7.8	.61	9.70	.172	.0256	.1366
.612	7.8	.65	9.87	.165	.0248	.1052
.628	11.5	3.53	9.66	.128	.0309	.0887
.628	11.5	3.45	9.70	.128	.0305	.0876
.624	11.6	5.13	9.66	.116	.0289	.0784
.612	11.8	6.85	9.74	.110	.0285	.0703
.632	11.4	2.69	9.74	.145	.0326	.0977
.628	11.5	1.69	9.58	.178	.0431	.1432

TABLE I.- DATA MEASURED FOR FLAT-BOTTOM PLANING SURFACE – Continued

(a) Shallow-water data – Continued

[ρ = 1.977 slugs/cu ft]

$\frac{z}{b}$	τ, deg	$\frac{l_m}{b}$	C_V	C_L	C_D	$C_{M_{te}}$	$\frac{z}{b}$	τ, deg	$\frac{l_m}{b}$	C_V	C_L	C_D	$C_{M_{te}}$
0.628	11.5	1.57	9.76	0.171	0.0405	0.1289	0.812	11.8	7.01	9.53	0.103	0.0278	0.0679
.628	11.5	1.65	9.72	.173	.0375	.1292	.812	11.8	6.89	9.66	.105	.0279	.0691
.624	11.6	.97	9.64	.215	.0460	.1433	.828	11.5	1.57	9.95	.170	.0431	.1429
.616	11.7	.73	9.68	.228	.0464	.1711	.824	11.6	.85	9.60	.226	.0512	.1649
.636	15.2	2.73	9.66	.197	.0575	.1355	.816	11.7	.53	9.74	.245	.0612	.2501
.632	15.3	2.65	9.66	.199	.0584	.1377	.828	15.4	1.49	9.72	.228	.0639	.1646
.636	15.2	3.57	9.70	.189	.0549	.1313	.828	15.4	1.45	9.72	.232	.0630	.1565
.632	15.3	5.25	9.78	.168	.0527	.1117	.828	15.4	1.49	9.72	.225	.0648	.1681
.632	15.3	2.01	9.62	.228	.0681	.1755	.832	15.3	1.93	9.66	.209	.0597	.1484
.628	15.4	1.41	9.66	.245	.0736	.1876	.832	15.3	2.77	9.74	.191	.0565	.1367
.624	15.5	1.25	9.47	.248	.0663	.1613	.832	15.3	3.57	9.70	.179	.0517	.1219
.620	15.6	.57	9.66	.350	.0945	.2758	.828	15.4	5.41	9.68	.159	.0507	.1058
.636	19.1	2.05	9.74	-----	.0979	------	.828	15.4	1.13	9.58	.263	.0791	.2088
.636	19.1	1.97	9.66	.275	.0961	.1790	.832	19.2	1.61	9.66	.274	.0942	.1767
.636	19.1	2.05	9.68	.271	.0971	.1827	.832	19.2	1.55	9.66	.282	.0990	.1928
.636	19.1	2.01	9.76	.273	.0979	.1814	.832	19.2	1.57	9.66	.285	.1013	.2056
.640	19.0	2.93	9.66	.253	.0910	.1734	.836	19.1	1.97	9.78	-----	.0951	------
.640	19.0	3.57	9.68	.236	.0836	.1550	.836	19.1	1.93	9.66	.267	.0957	.1917
.632	19.2	1.61	9.64	-----	.1106	------	.840	19.0	2.73	9.62	.249	.0883	.1744
.632	19.2	1.49	9.64	.314	.1154	.2527	.840	19.0	5.65	9.76	.227	.0840	.1526
.628	19.3	1.05	9.66	.346	------	------	.820	19.5	.61	9.64	.391	.1430	.3095
.628	19.3	1.09	9.82	.331	.1139	.2278							
.624	19.4	.69	9.91	.392	.1432	.3987	1.008	3.9	2.71	9.62	.027	.0061	.0236
.620	19.5	.65	9.74	.408	.1393	.3157	1.008	3.9	2.69	9.58	.027	.0061	.0224
							1.008	3.9	2.61	9.89	.029	.0073	.0271
.808	3.9	4.65	9.26	.056	.0065	.0475	1.008	3.9	3.29	9.28	.024	.0063	.0201
.808	3.9	4.85	10.01	.022	.0069	.0190	1.008	3.9	3.31	9.32	.024	.0064	.0201
.808	3.9	4.89	9.66	.022	.0065	.0178	1.008	3.9	5.05	9.66	.020	.0067	.0178
.808	3.9	4.87	9.66	.022	.0067	.0190	1.008	3.9	6.41	9.60	.019	.0071	.0155
.808	3.9	6.29	9.66	.021	.0071	.0167	1.008	3.9	6.77	9.68	.019	.0065	.0143
.808	3.9	6.37	9.70	.019	.0067	.0155	1.008	3.9	1.29	9.68	.048	.0109	.0588
.808	3.9	3.29	9.57	.028	.0082	.0260	1.008	3.9	1.49	9.68	.050	.0075	.0498
.808	3.9	2.29	9.57	.036	.0075	.0317	1.008	3.9	1.41	9.66	.049	.0093	.0498
.808	3.9	1.81	9.62	.037	.0728	.0327	1.008	3.9	.89	9.66	.064	.0055	.0374
.808	3.9	1.17	9.68	.053	.0118	.0655	1.012	7.8	1.49	9.58	.099	.0160	.0742
.808	3.9	1.17	8.74	.052	.0035	.0207	1.012	7.8	1.53	9.53	.095	.0151	.0673
.808	3.9	.73	10.51	.069	.0087	.0447	1.020	7.7	1.45	10.16	.097	.0143	.0626
.808	3.9	.77	9.91	.067	.0028	.0168	1.020	7.7	1.89	9.68	.084	.0157	.0643
.808	3.9	.53	9.68	.093	.0134	.1402	1.020	7.7	1.77	9.76	.087	.0169	.0700
.808	3.9	.57	9.70	.084	.0091	.0668	1.020	7.7	1.73	9.78	.090	.0141	.0653
.808	3.9	.73	9.68	.069	.0097	.0872	1.020	7.7	2.73	9.66	.073	.0138	.0530
.808	3.9	.93	9.64	.059	.0069	.0499	1.020	7.7	5.09	9.62	.058	.0119	.0368
.820	7.7	2.57	9.66	.075	------	------	1.012	7.8	6.41	9.70	.068	.0132	.0512
.820	7.7	2.61	9.91	.074	.0140	.0565	1.008	7.9	6.37	9.62	.054	.0121	.0381
.820	7.7	2.69	9.74	.075	.0137	.0553	1.012	7.8	.85	9.58	.138	.0232	.1231
.820	7.7	2.65	9.66	.075	.0151	.0494	1.012	7.8	.77	9.76	.147	.0190	.0785
.820	7.7	2.61	9.58	.075	.0139	.0542	1.012	7.8	.73	9.66	.152	.0254	.1163
.820	7.7	3.45	9.66	.071	.0141	.0521	1.024	11.6	1.01	10.43	.183	.0431	.1436
.820	7.7	3.45	9.70	.070	.0142	.0532	1.024	11.6	1.09	9.82	.176	.0385	.1110
.812	7.8	5.09	9.57	.062	.0131	.0451	1.024	11.6	1.01	9.86	.189	.0431	.1516
.812	7.8	5.13	9.62	.062	.0133	.0440	1.024	11.6	1.45	9.74	.164	.0350	.1206
.808	7.9	6.49	9.70	.058	.0128	.0393	1.024	11.6	1.81	9.66	.153	.0353	.1190
.820	7.7	1.81	9.64	.101	.0193	.0851	1.024	11.6	1.77	9.62	.157	.0362	.1213
.820	7.7	1.77	9.57	.101	.0188	.0793	1.028	11.5	2.61	9.68	.131	.0297	.0977
.812	7.8	1.09	9.58	.126	.0223	.1145	1.028	11.5	2.65	9.62	.134	.0316	.1024
.812	7.8	.69	9.66	-----	.0184	------	1.028	11.5	3.49	9.66	.116	.0279	.0840
.808	7.9	.29	9.68	.201	.0206	------	1.024	11.6	5.41	9.70	.107	.0281	.0737
.812	7.8	.65	9.89	.161	.0203	.0476	1.012	11.8	6.69	9.76	.102	.0269	.0679
.824	11.6	1.89	9.55	.142	.0322	.0993	1.016	11.7	.57	9.74	.248	.0531	.1620
.828	11.5	1.97	9.95	.140	.0317	.0959	1.024	15.5	1.01	9.68	.252	.0707	.1767
.824	11.6	1.89	9.66	.143	.0326	.0982	1.016	15.7	1.05	9.66	.247	.0674	.1519
.828	11.5	2.85	9.66	.133	.0312	.0931	1.028	15.4	1.49	9.66	.225	.0667	.1739
.828	11.5	2.81	9.68	.132	.0314	.0943	1.032	15.3	2.73	9.66	.182	.0534	.1308
.828	11.5	3.49	9.78	.125	.0302	.0923	1.028	15.4	2.01	9.74	.206	.0589	.1544
.824	11.6	5.41	9.74	.108	.0280	.0737	1.032	15.3	3.49	9.78	.175	.0545	.1266

TABLE I.- DATA MEASURED FOR FLAT-BOTTOM PLANING SURFACE — Continued

(a) Shallow-water data — Concluded

[ρ = 1.977 slugs/cu ft]

$\frac{z}{b}$	τ, deg	$\frac{l_m}{b}$	C_V	C_L	C_D	$C_{M_{te}}$	$\frac{z}{b}$	τ, deg	$\frac{l_m}{b}$	C_V	C_L	C_D	$C_{M_{te}}$
1.020	15.6	0.57	9.72	0.341	0.1012	0.2955	1.228	15.4	1.93	9.62	0.205	0.0585	0.1496
1.024	19.4	1.05	9.58	.313	.1075	.2022	1.232	15.3	3.61	9.72	.168	.0528	.1231
1.024	19.4	1.01	9.66	.330	.1121	.2314	1.220	19.5	.69	9.62	.368	.1240	.3263
1.032	19.2	1.69	9.66	.280	.0997	.2049	1.224	19.4	1.13	9.66	.302	.1024	.2042
1.032	19.2	1.69	9.68	.279	.0996	.2037	1.228	19.3	1.53	9.66	.274	.0935	.1799
1.032	19.2	1.97	9.62	.270	.0932	.1989	1.232	19.2	1.73	9.68	.275	.1003	.2097
1.036	19.1	2.93	9.66	.233	.0862	.1651	1.236	19.1	2.97	9.72	.233	.0876	.1722
1.040	19.0	3.61	9.72	.229	.0869	.1621	1.236	19.1	3.73	9.74	-----	------	------
1.208	3.9	2.43	9.66	.031	.0077	.0305	1.608	3.9	.93	9.68	.053	.0116	.0817
1.208	3.9	3.37	9.82	.024	.0072	.0213	1.608	3.9	1.09	9.66	.048	.0079	.0504
1.208	3.9	3.35	9.82	.024	.0067	.0213	1.608	3.9	2.09	9.66	.032	.0060	.0305
1.208	3.9	4.69	9.62	.022	.0059	.0178	1.608	3.9	2.17	9.66	.031	.0054	.0258
1.208	3.9	6.81	9.64	.016	.0063	.0131	1.608	3.9	2.65	9.66	.026	.0082	.0271
1.220	7.7	1.29	9.74	.105	.0159	.0680	1.608	3.9	3.77	9.74	.023	.0068	.0201
1.220	7.7	1.33	9.78	.107	.0165	.0843	1.608	3.9	5.09	9.41	.022	.0077	.0190
1.220	7.7	1.37	10.09	.102	.0169	.0706	1.608	3.9	5.49	9.60	.019	.0069	.0155
1.220	7.7	1.33	9.68	.107	.0168	.0831	1.612	7.8	1.01	9.64	.124	.0164	.1482
1.212	7.8	1.33	9.66	.105	.0149	.0704	1.620	7.7	1.45	9.68	.100	.0176	.0869
1.220	7.7	1.77	9.66	.088	.0149	.0653	1.620	7.7	1.49	9.76	.097	.0177	.0742
1.220	7.7	1.77	9.66	.088	.0141	.0618	1.612	7.8	1.49	9.58	.097	.0165	.0750
1.220	7.7	2.13	9.66	.082	.0138	.0598	1.620	7.7	2.77	9.62	.071	.0143	.0542
1.220	7.7	2.53	9.64	.074	.0130	.0553	1.620	7.7	3.45	9.70	.065	.0139	.0509
1.220	7.7	3.53	9.66	.067	.0143	.0532	1.612	7.8	5.09	9.66	.055	.0136	.0416
1.212	7.8	5.09	10.05	.058	.0126	.0416	1.612	11.8	.53	9.68	.231	.0436	.1011
1.212	7.8	4.85	9.33	.059	.0127	.0440	1.616	11.7	.73	9.68	.221	.0459	.1834
1.212	7.8	4.77	9.58	.059	.0130	.0440	1.624	11.6	1.09	9.70	.182	.0398	.1317
1.208	7.9	6.85	9.68	.053	.0126	.0381	1.624	11.6	1.57	9.57	.156	.0344	.1150
1.208	7.9	6.77	9.74	.053	.0126	.0381	1.624	11.6	2.09	9.68	.136	.0310	.0960
1.216	11.7	.77	9.68	.210	.0416	.1380	1.628	11.5	2.77	9.66	.121	.0317	.0931
1.224	11.6	.97	9.66	.198	.0420	.1661	1.628	11.5	3.49	9.66	.115	.0286	.0852
1.224	11.6	1.09	9.45	.191	.0418	.1534	1.620	15.6	.61	9.68	.311	.0800	.2280
1.224	11.6	1.21	9.91	.180	.0381	.1243	1.624	15.5	1.17	9.62	.245	.0686	.1711
1.224	11.6	1.49	9.66	.157	.0346	.1148	1.628	15.4	1.61	9.74	.216	.0637	.1616
1.224	11.6	1.81	9.62	.151	.0337	.1108	1.632	15.3	2.01	9.82	.199	.0597	.1486
1.228	11.5	2.49	9.70	.133	.0303	.0988	1.628	15.4	1.89	9.66	.208	.0614	.1543
1.224	11.6	3.49	9.58	.115	.0291	.0852	1.632	15.3	2.81	9.68	.179	.0532	.1308
1.224	11.6	5.09	9.76	.102	.0274	.0713	1.616	19.6	.57	9.68	.373	.1246	.2441
1.224	15.5	1.21	9.76	.238	.0655	.1680	1.628	19.3	1.09	9.76	.309	.1090	.1958
1.224	15.5	1.21	9.76	.234	.0655	.1577	1.632	19.2	1.73	9.72	.272	.0995	.2109
1.228	15.4	1.53	9.64	.228	.0594	.1578	1.632	19.2	2.01	9.66	.260	.0962	.2071

TABLE I.- DATA MEASURED FOR FLAT-BOTTOM PLANING SURFACE – Concluded

(b) Deepwater data

[ρ = 1.938 slugs/cu ft]

$\frac{z}{b}$	τ, deg	$\frac{l_m}{b}$	C_V	C_L	C_D	$C_{M_{te}}$
28.8	3.9	5.13	9.78	0.018	0.0065	0.0154
28.8	3.9	4.97	9.78	.018	.0058	.0154
28.8	3.9	5.93	9.87	.016	.0060	.0131
28.8	7.8	.85	9.82	.128	.0200	.1152
28.8	7.8	.81	9.74	.131	.0190	.1024
28.8	7.8	1.53	9.74	.092	.0179	.0847
28.8	7.7	2.29	9.74	.077	.0146	.0622
28.8	7.7	2.37	9.76	.074	.0139	.0576
28.8	7.8	3.13	9.86	.064	.0139	.0520
28.8	7.8	4.05	9.82	.056	------	------
28.8	7.9	4.01	9.86	.056	.0122	.0439
28.8	7.9	5.77	9.60	.048	.0113	.0369
28.8	7.9	6.41	9.64	.047	.0111	.0357
28.8	11.6	.85	9.60	.204	.0445	.1784
28.8	11.6	1.65	9.47	.150	.0344	.1176
28.8	11.6	1.65	9.66	.150	.0346	.1187
28.8	11.6	2.61	9.78	.121	.0296	.0977
28.8	11.6	3.41	9.57	.108	.0271	.0816
28.8	11.6	3.33	9.76	.107	.0263	.0804
28.8	11.7	4.17	9.74	.100	.0262	.0759
28.8	11.7	4.21	9.78	.100	.0262	.0747
28.8	11.8	5.89	9.70	.090	.0244	.0655
28.8	11.9	6.77	9.66	.088	.0246	.0632
28.8	11.9	6.81	9.64	.088	.0242	.0620
28.8	15.6	.93	9.70	.255	.0691	.1862
28.8	15.4	1.81	9.70	.197	.0578	.1505
28.8	15.4	2.65	9.70	.169	.0512	.1295
28.8	15.4	2.73	9.49	.165	.0503	.1273
28.8	15.4	2.73	9.58	.168	.0499	.1273
28.8	15.4	3.45	9.66	.152	.0473	.1148
28.8	15.4	3.41	9.66	.155	.0474	.1158
28.8	15.5	4.33	9.70	.142	.0456	.1055
28.8	15.7	5.97	9.66	.134	.0438	.0952
28.8	15.7	.992	9.80	.132	.0434	.0940
28.8	19.4	.950	9.82	.317	.1126	.2611
28.8	19.2	.974	9.86	.253	.0928	.1999
28.8	19.2	.974	9.74	.256	.0952	.2092
28.8	19.2	.981	9.76	.226	.0863	.1789
28.8	19.1	.986	9.78	.210	.0822	.1597
28.8	19.2	.986	9.70	.206	.0799	.1585
28.8	19.2	.989	9.70	.193	.0759	.1353

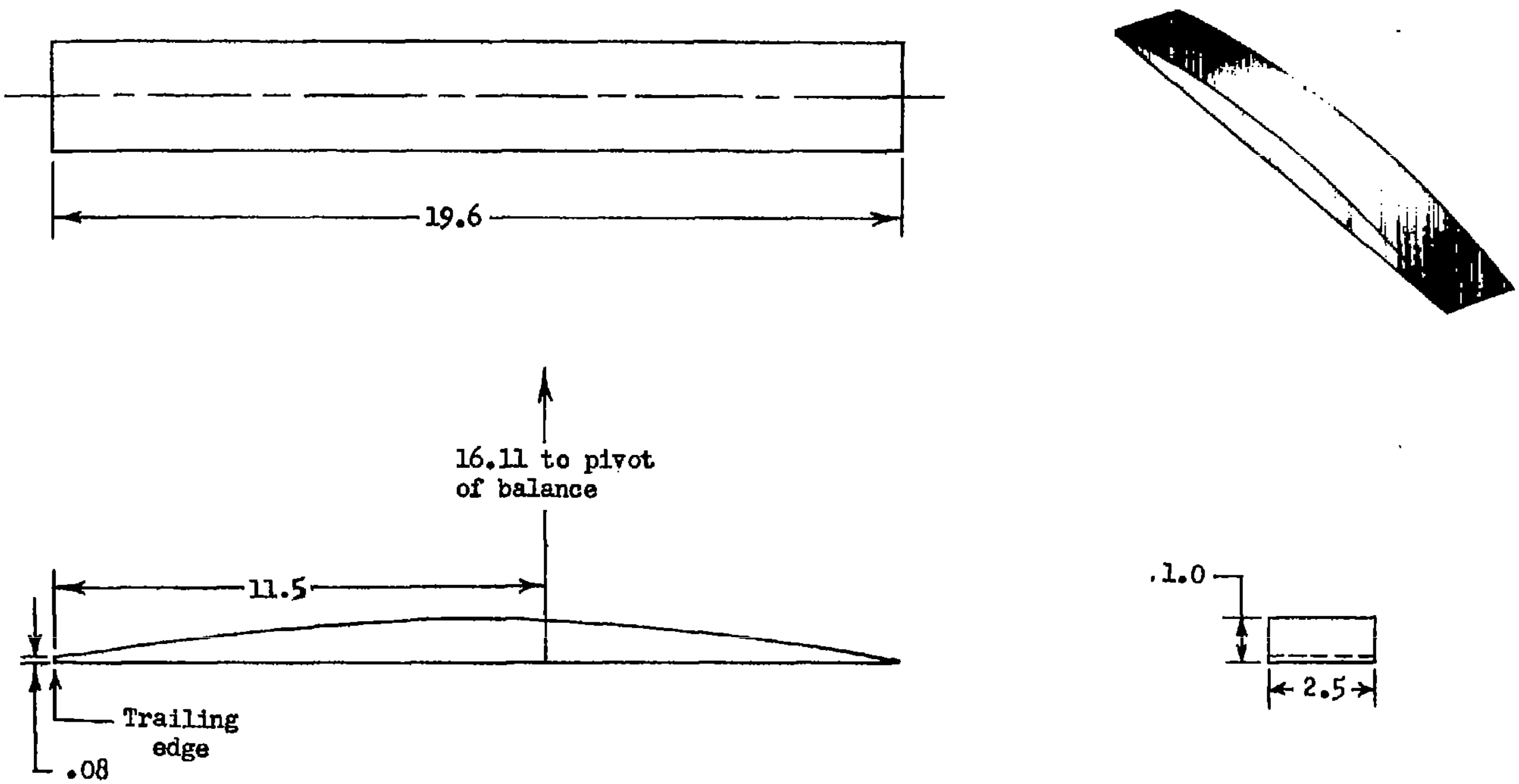


Figure 1.- Details of planing surface. All dimensions are in inches.

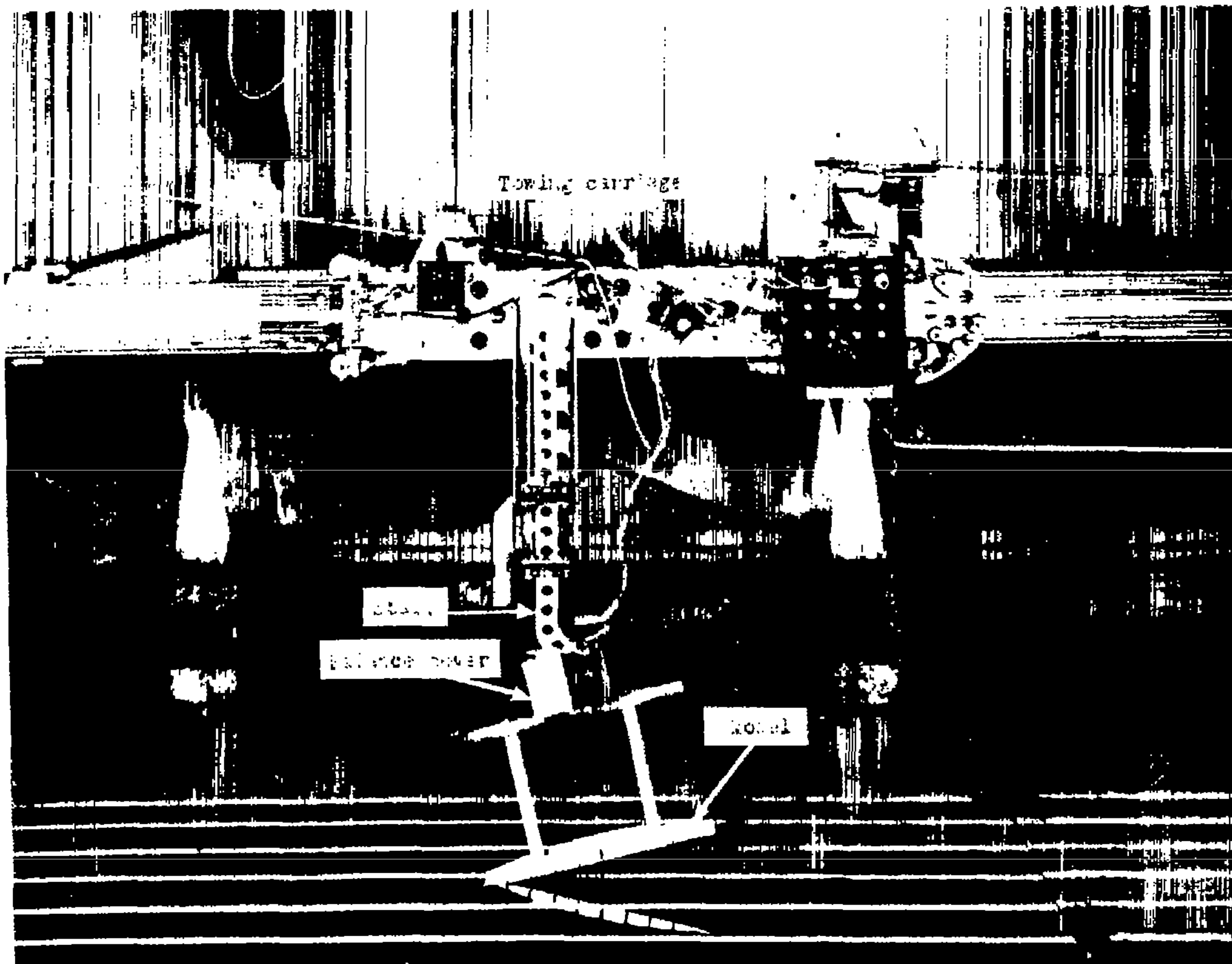


Figure 2.- Photograph of test setup. L-87630.1

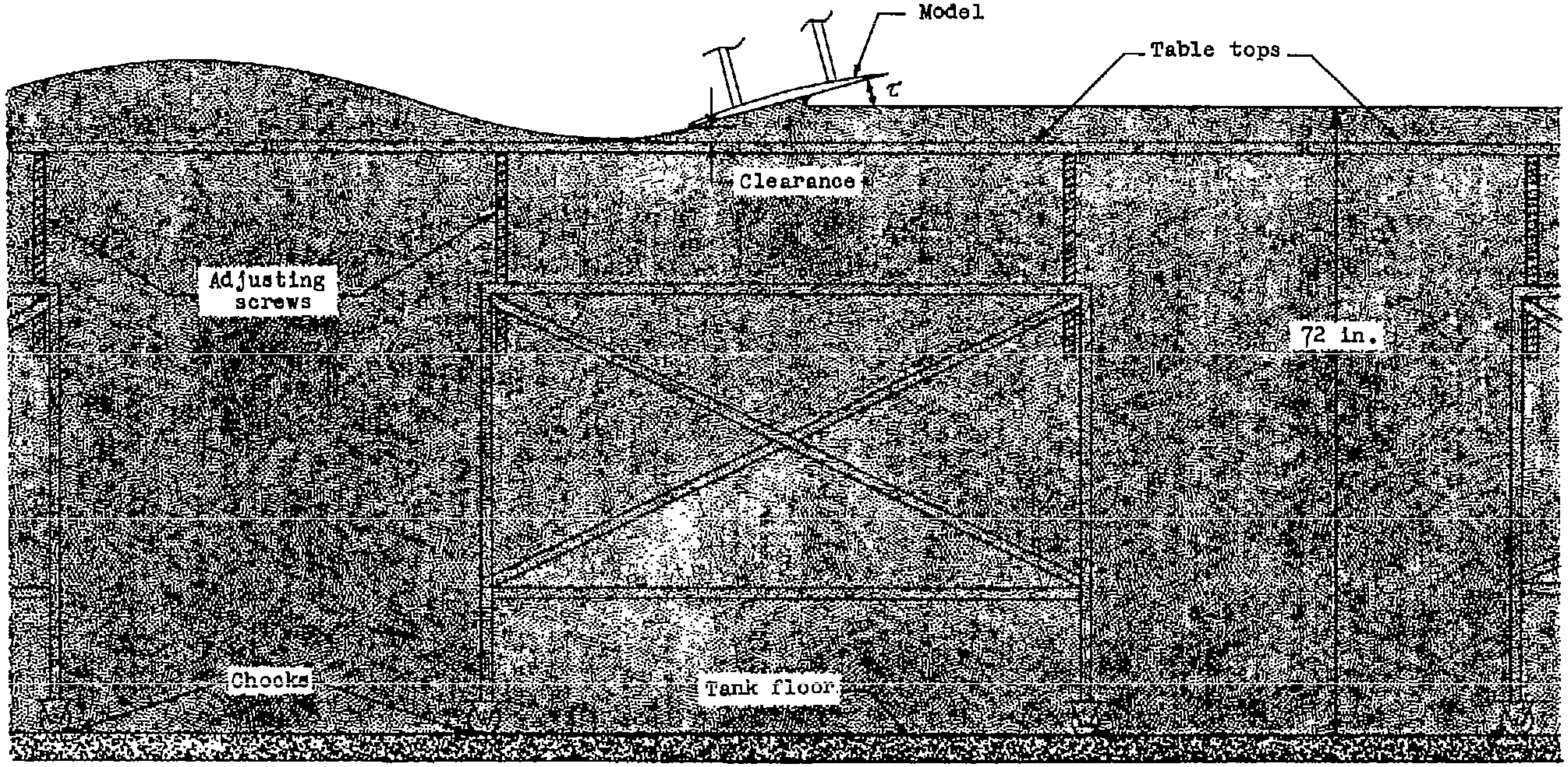
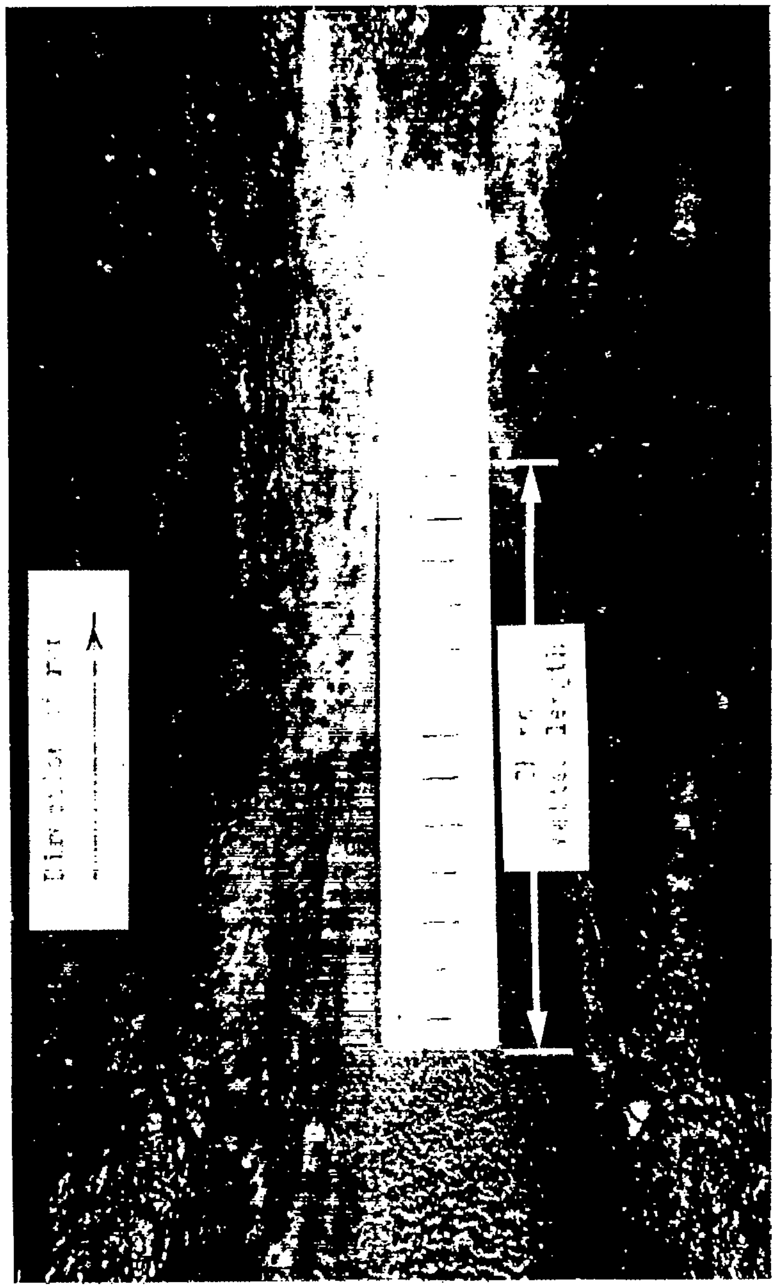


Figure 3.- Sketch of test setup.



L-91761

Figure 4.- Underwater photograph of model. Trim, 12°; clearance, 0.5 inch.

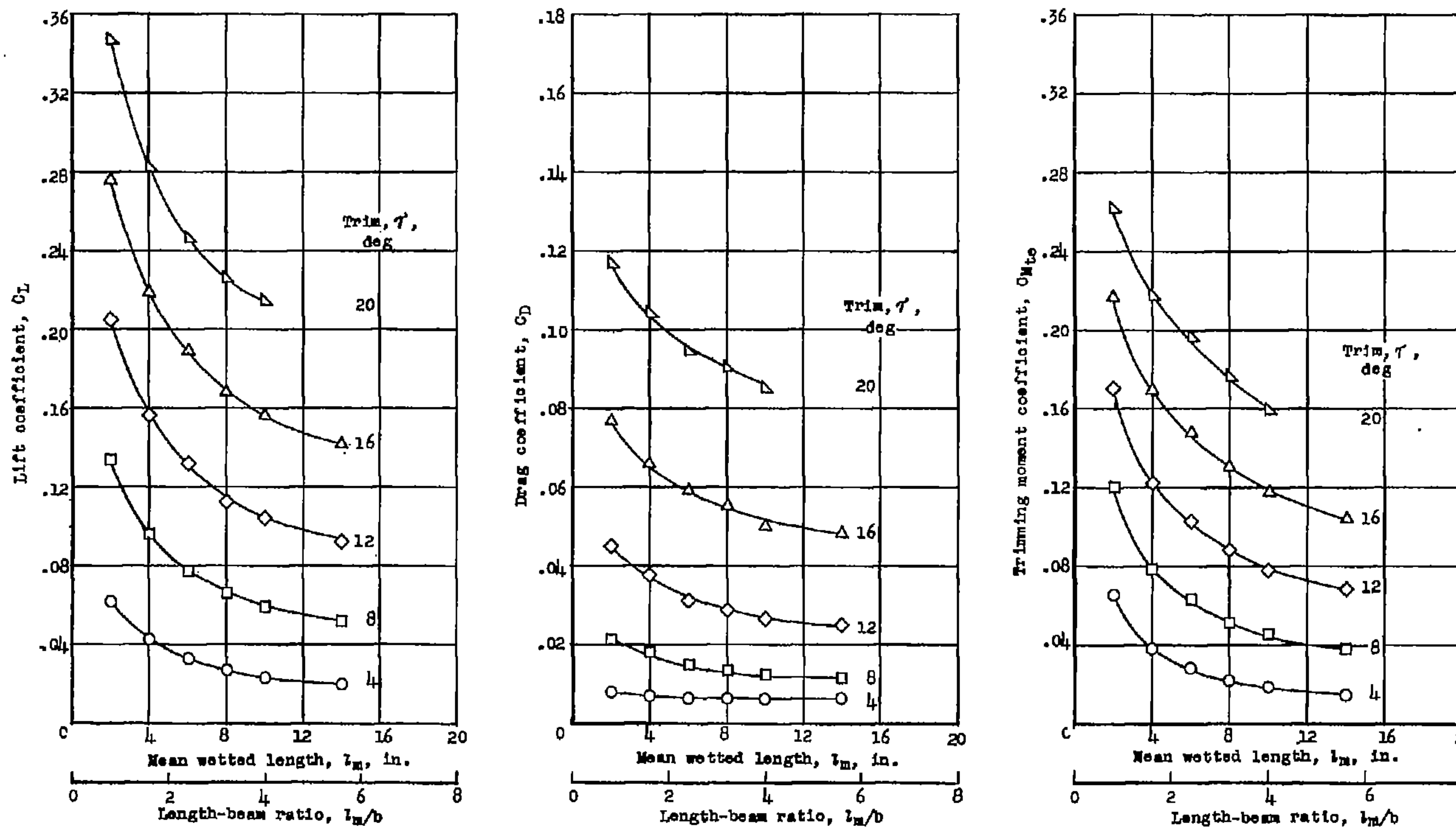
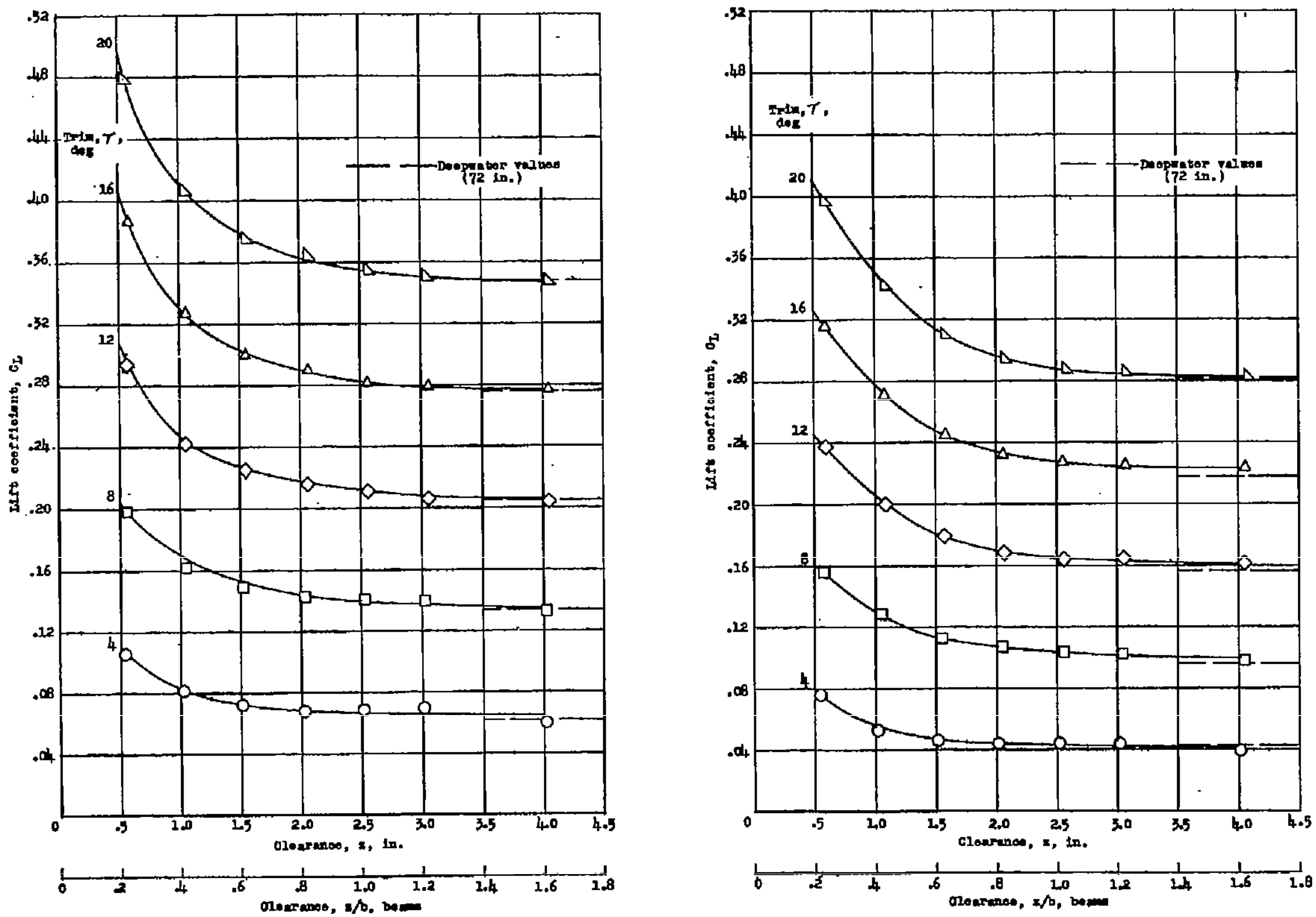


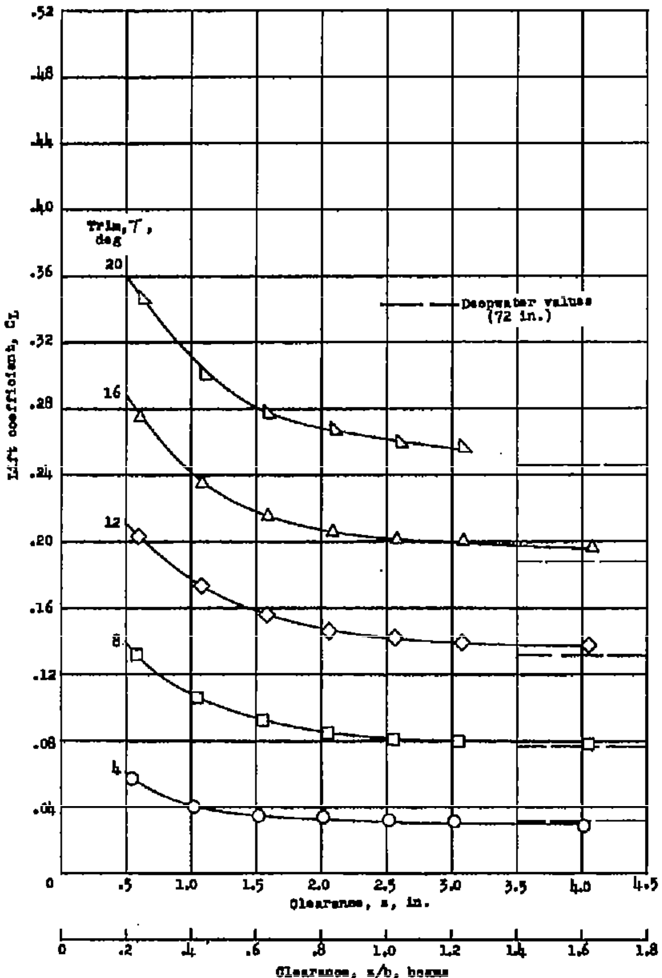
Figure 5.- Lift, drag, and trimming-moment coefficients for deep water (72 inches).



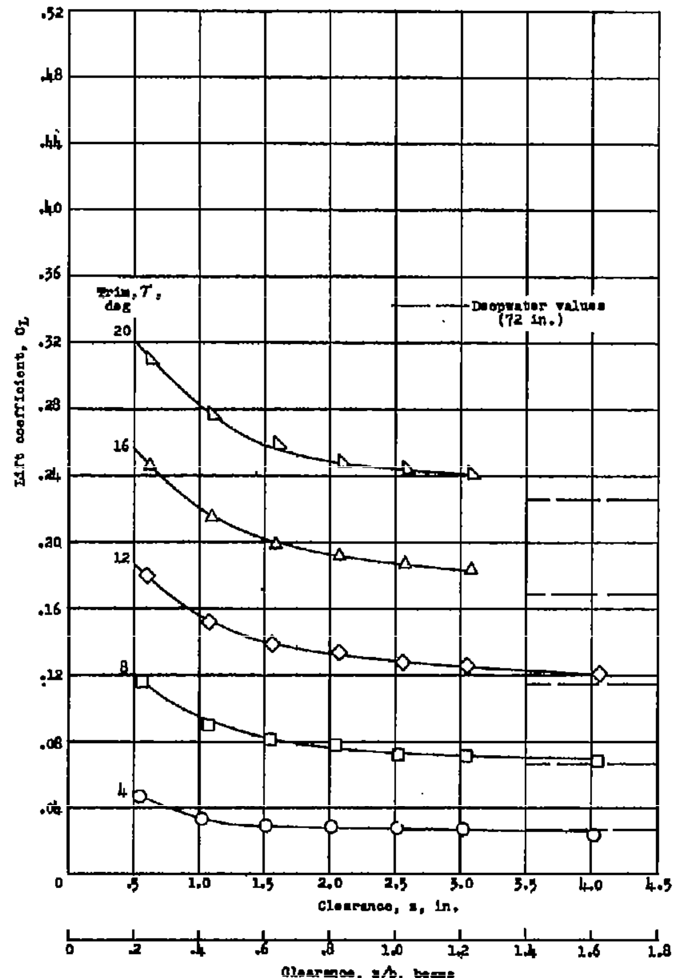
(a) Mean wetted length $l_m = 2$ inches ($l_m/b = 0.8$).

(b) Mean wetted length $l_m = 4$ inches ($l_m/b = 1.6$).

Figure 6.- Effect of clearance on lift coefficient.

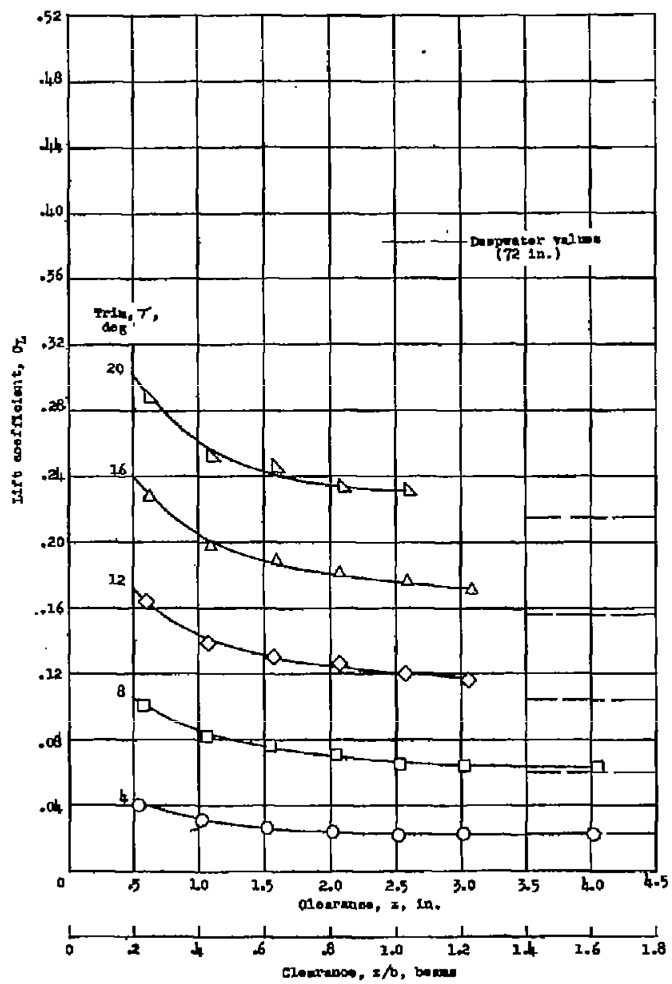


(c) Mean wetted length $l_m = 6$ inches ($l_m/b = 2.4$).

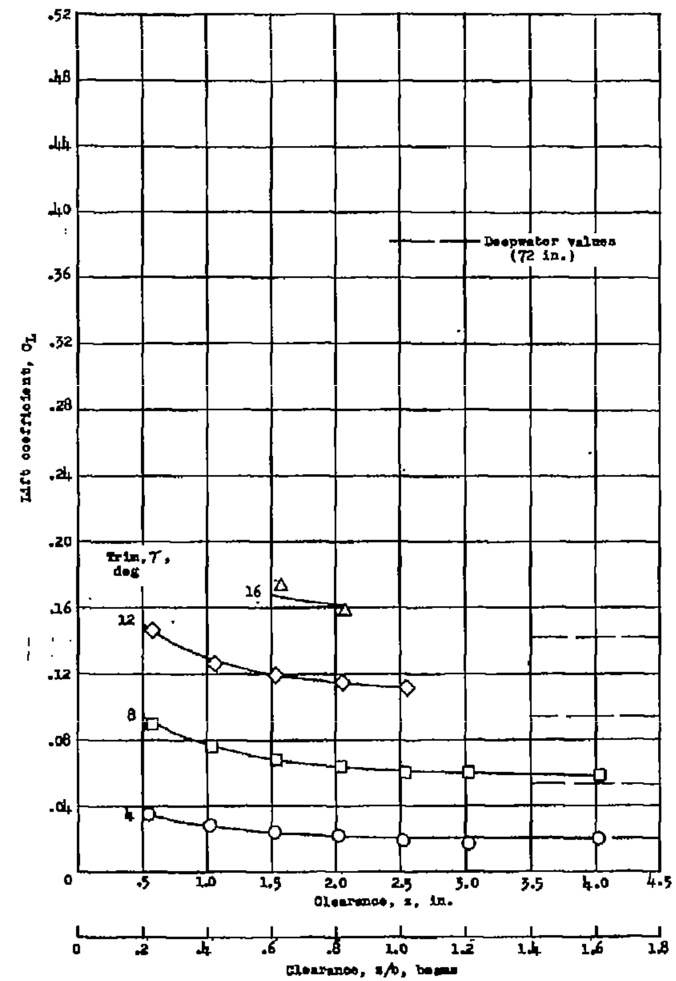


(d) Mean wetted length $l_m = 8$ inches ($l_m/b = 3.2$).

Figure 6.- Continued.

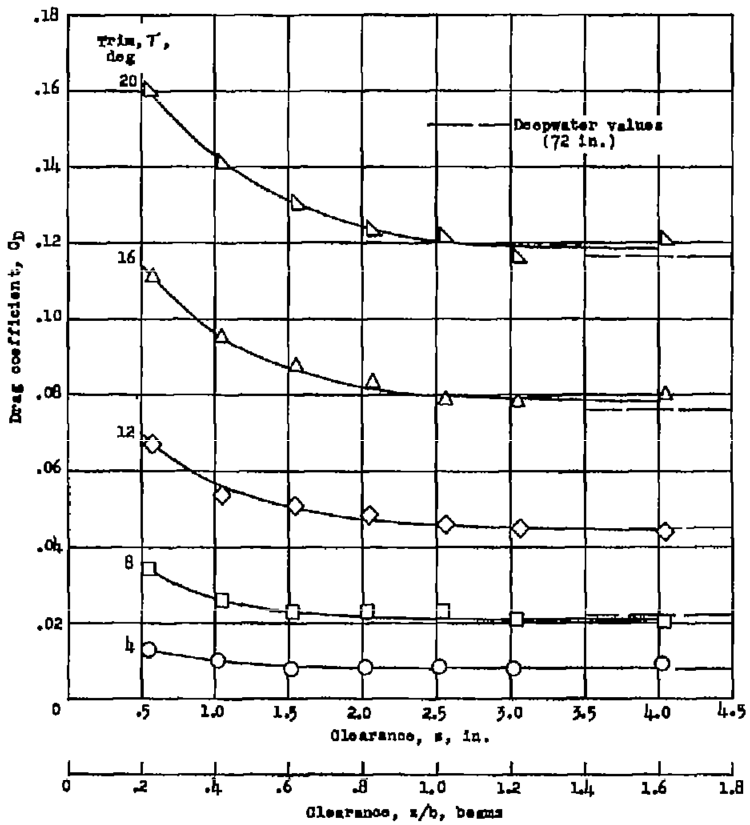


(e) Mean wetted length l_m = 10 inches ($l_m/b = 4.0$).

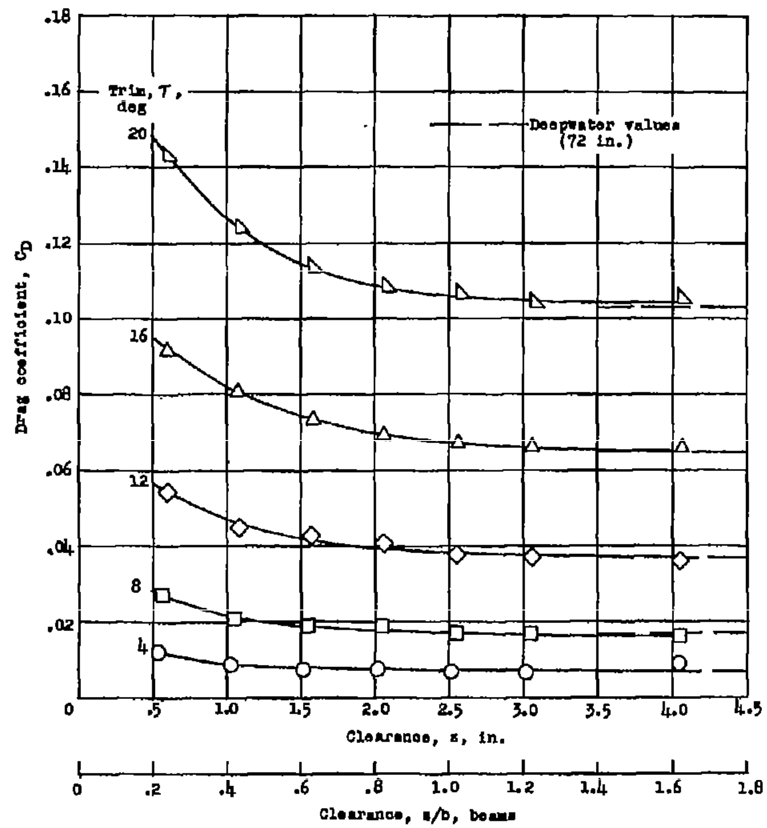


(f) Mean wetted length l_m = 14 inches ($l_m/b = 5.6$).

Figure 6.- Concluded.

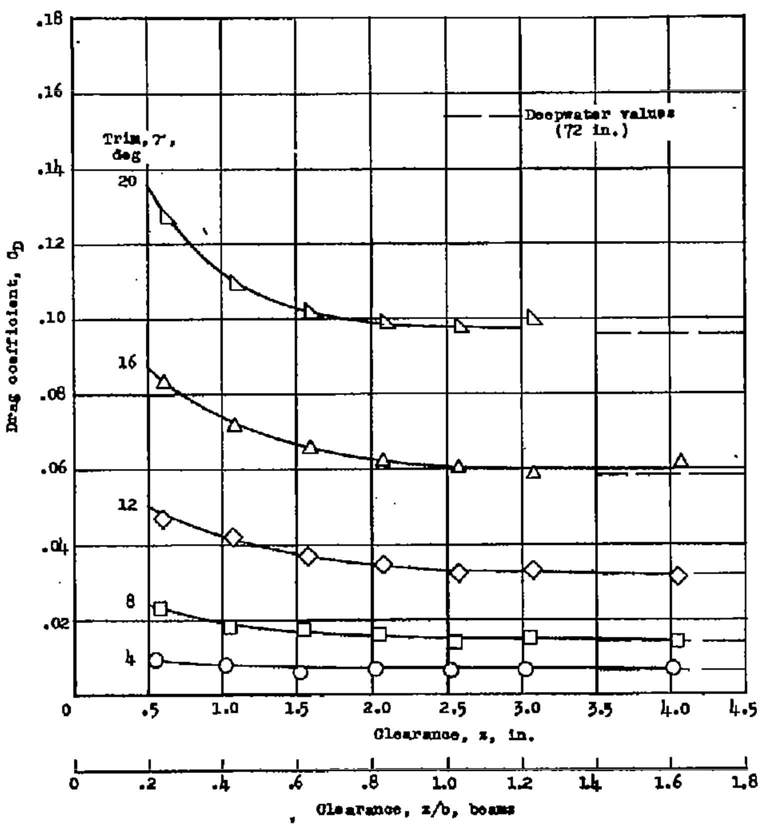


(a) Mean wetted length l_m = 2 inches (l_m/b = 0.8).

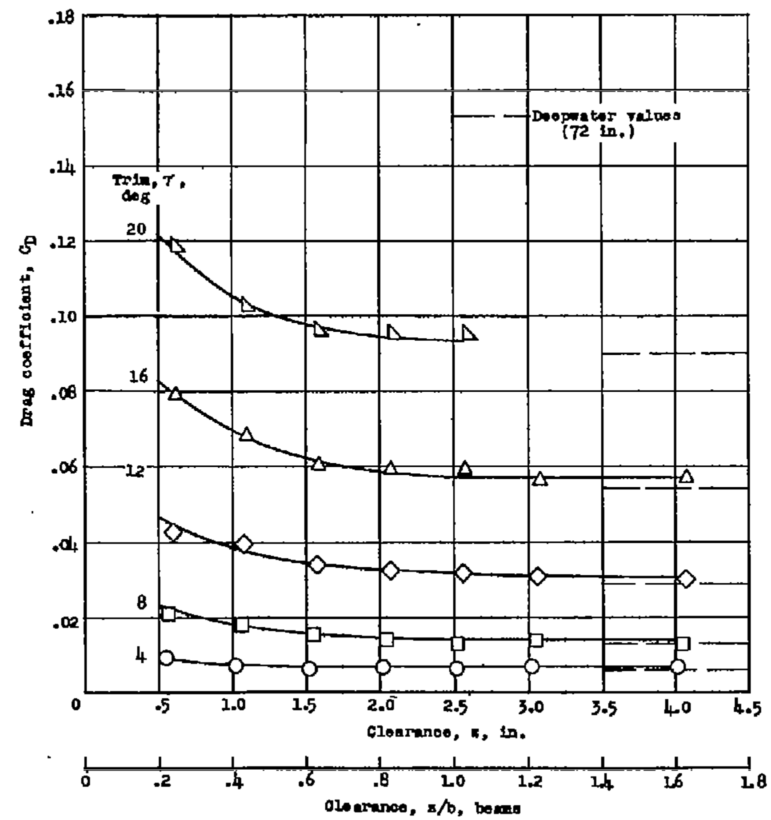


(b) Mean wetted length l_m = 4 inches (l_m/b = 1.6).

Figure 7.- Effect of clearance on drag coefficient.

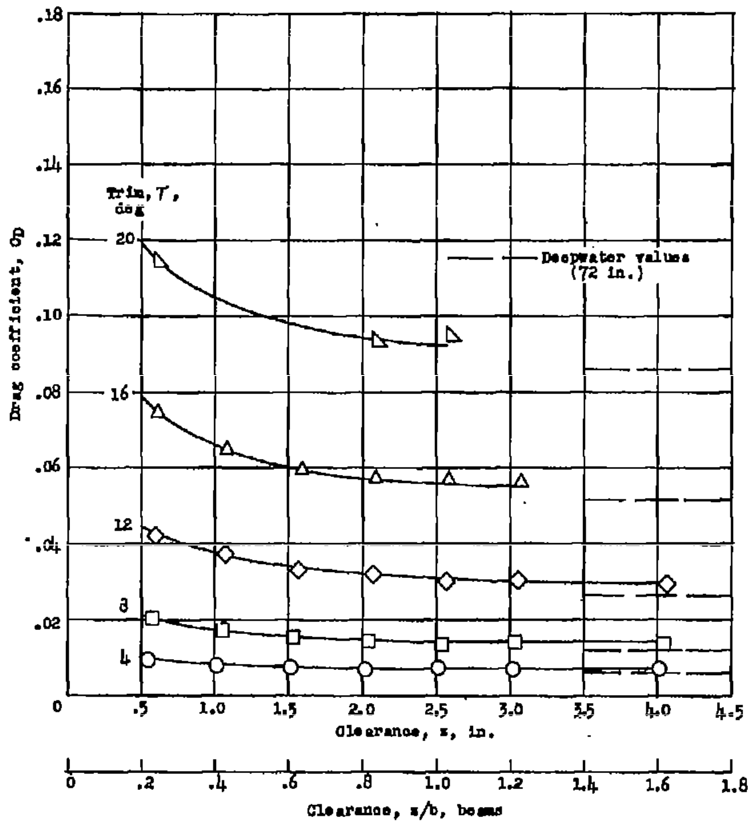


(c) Mean wetted length l_m = 6 inches (l_m/b = 2.4).

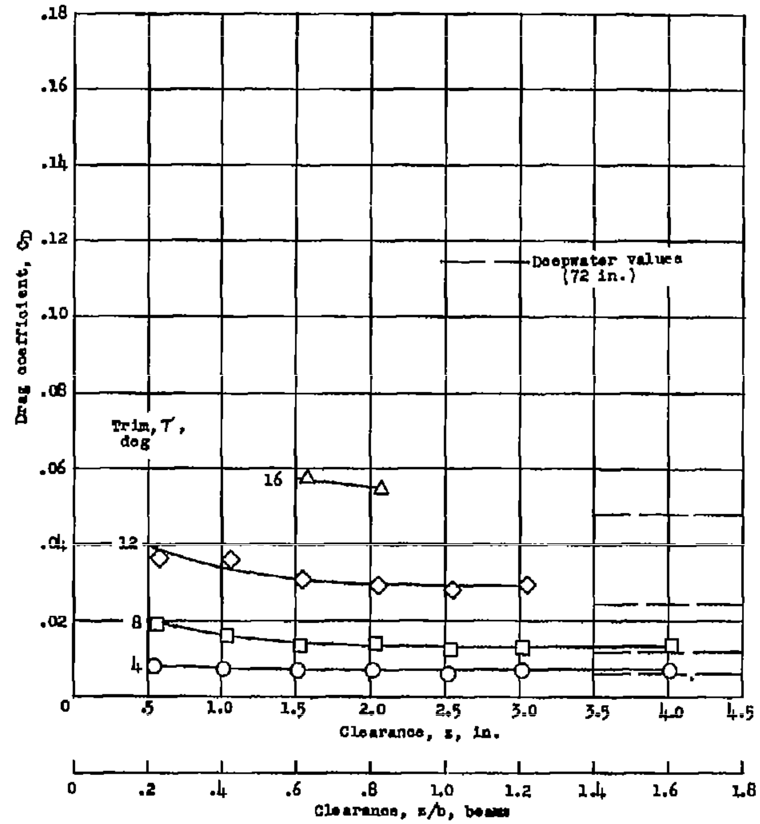


(d) Mean wetted length l_m = 8 inches (l_m/b = 3.2).

Figure 7.- Continued.

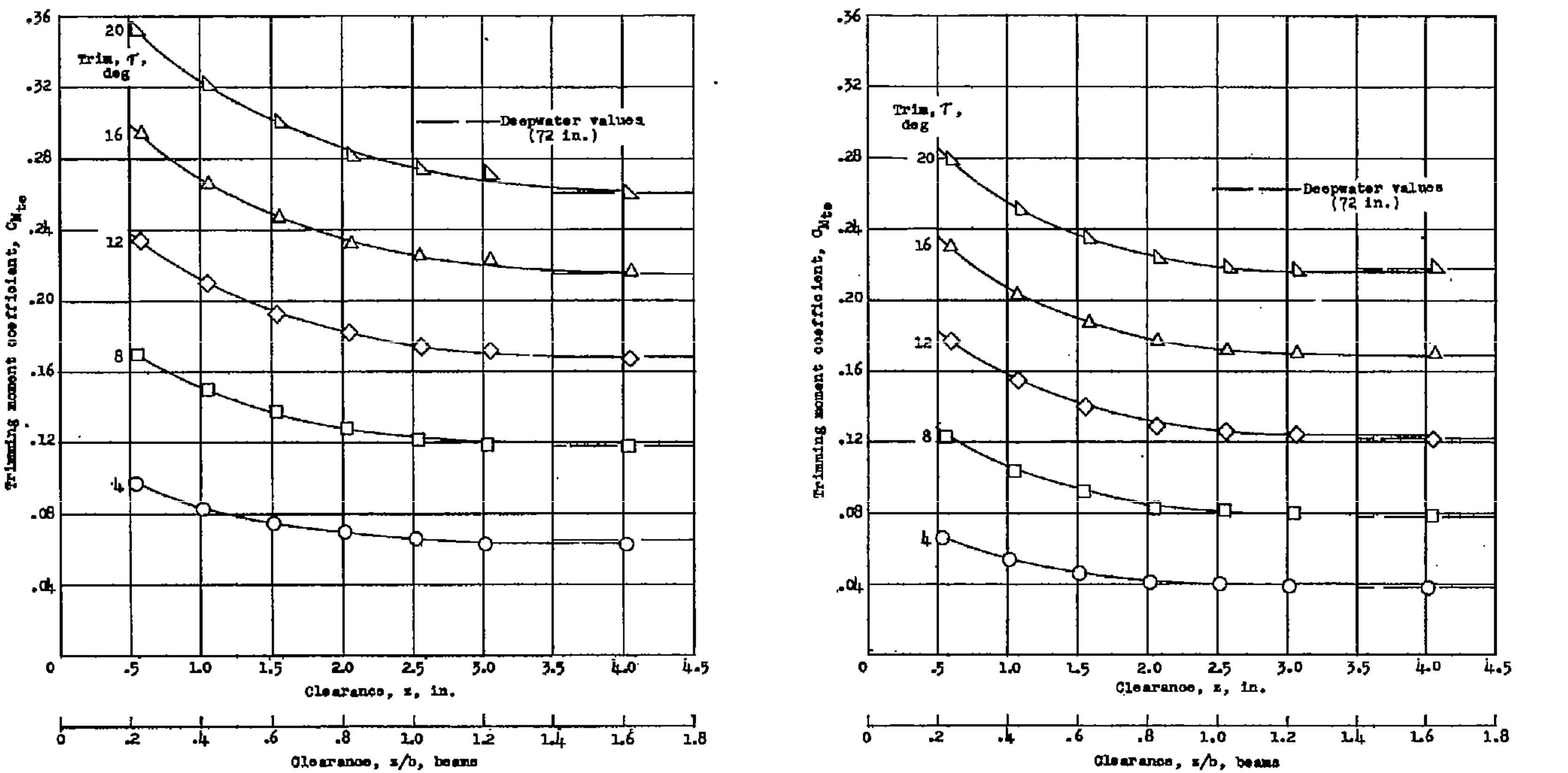


(e) Mean wetted length l_m = 10 inches ($l_m/b = 4.0$).



(f) Mean wetted length l_m = 14 inches ($l_m/b = 5.6$).

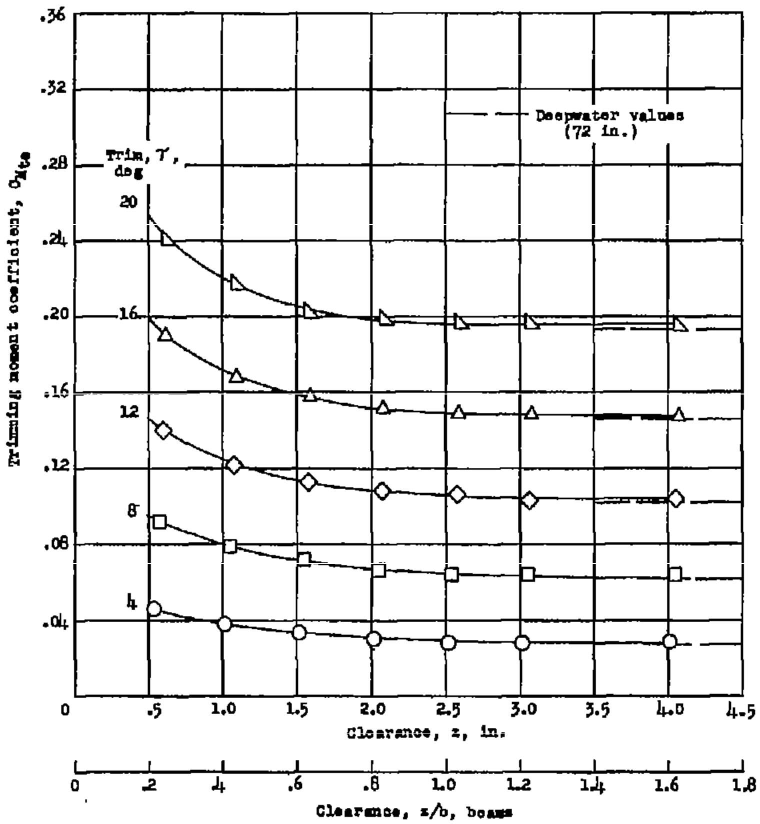
Figure 7.- Concluded.



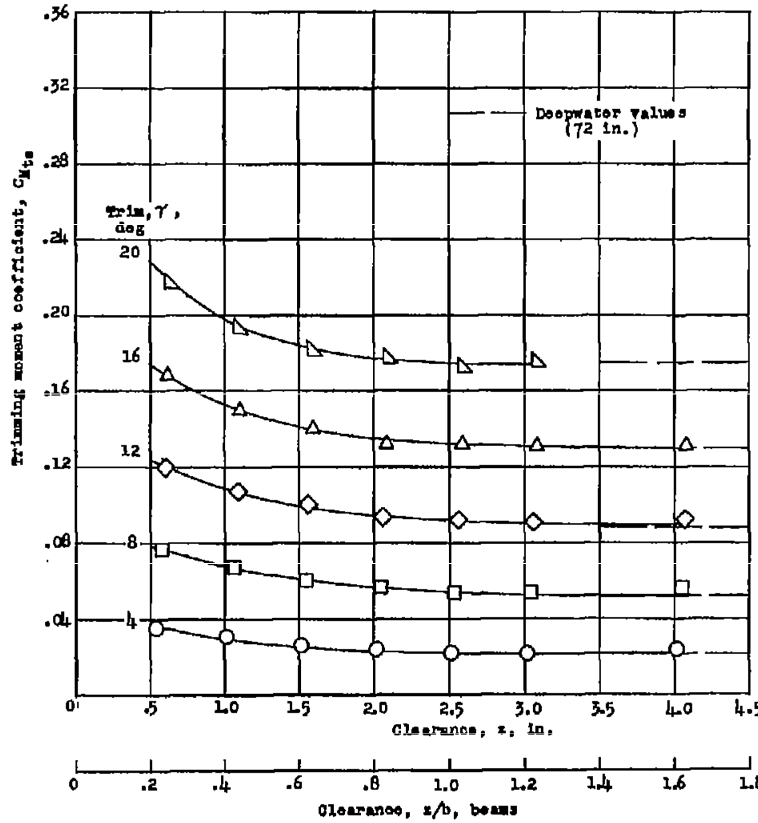
(a) Mean wetted length l_m = 2 inches (l_m/b = 0.8).

(b) Mean wetted length l_m = 4 inches (l_m/b = 1.6).

Figure 8.- Effect of clearance on trimming-moment coefficient.

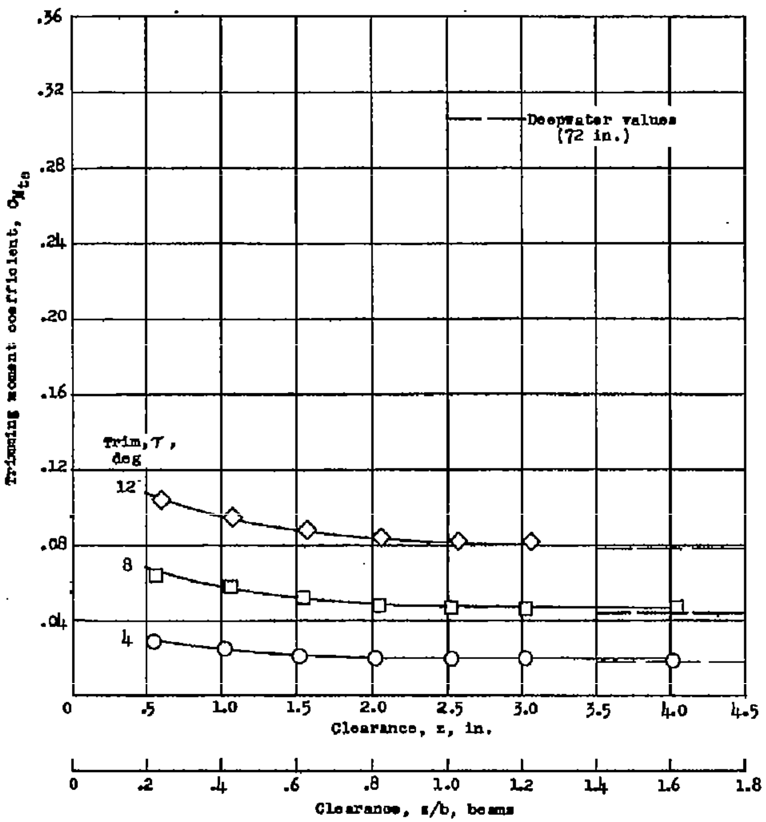


(c) Mean wetted length $l_m = 6$ inches ($l_m/b = 2.4$).

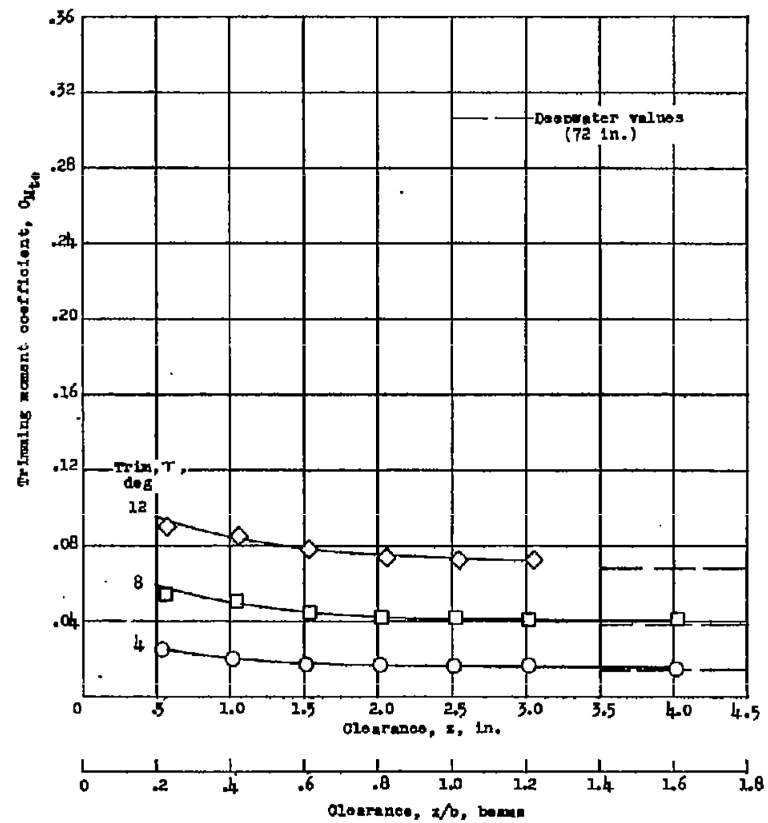


(d) Mean wetted length $l_m = 8$ inches ($l_m/b = 3.2$).

Figure 8.- Continued.

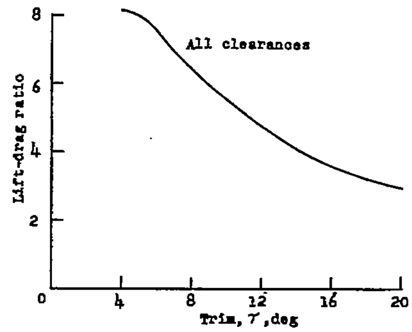


(e) Mean wetted length l_m = 10 inches (l_m/b = 4.0).

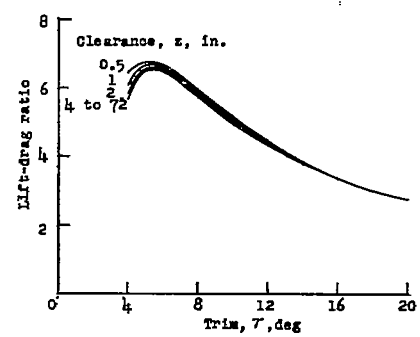


(f) Mean wetted length l_m = 14 inches (l_m/b = 5.6).

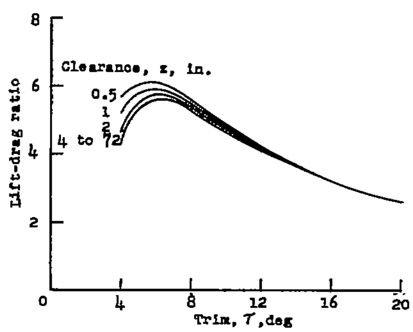
Figure 8.- Concluded.



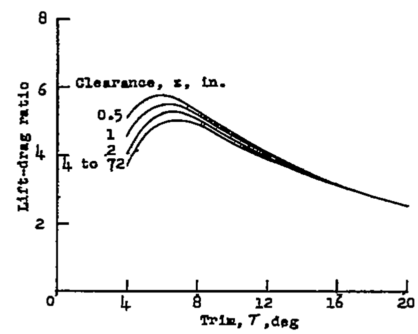
(a) Mean wetted length
l_m = 2 inches
(l_m/b = 0.8).



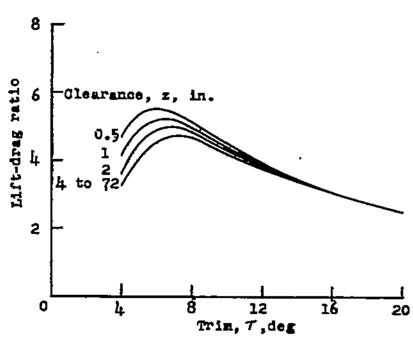
(b) Mean wetted length
l_m = 4 inches
(l_m/b = 1.6).



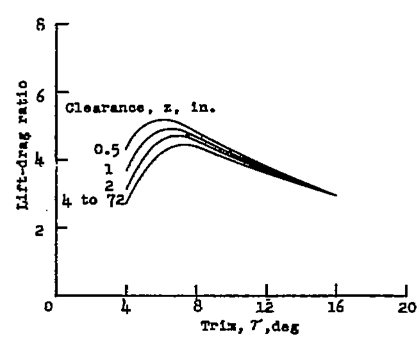
(c) Mean wetted length
l_m = 6 inches
(l_m/b = 2.4).



(d) Mean wetted length
l_m = 8 inches
(l_m/b = 3.2).

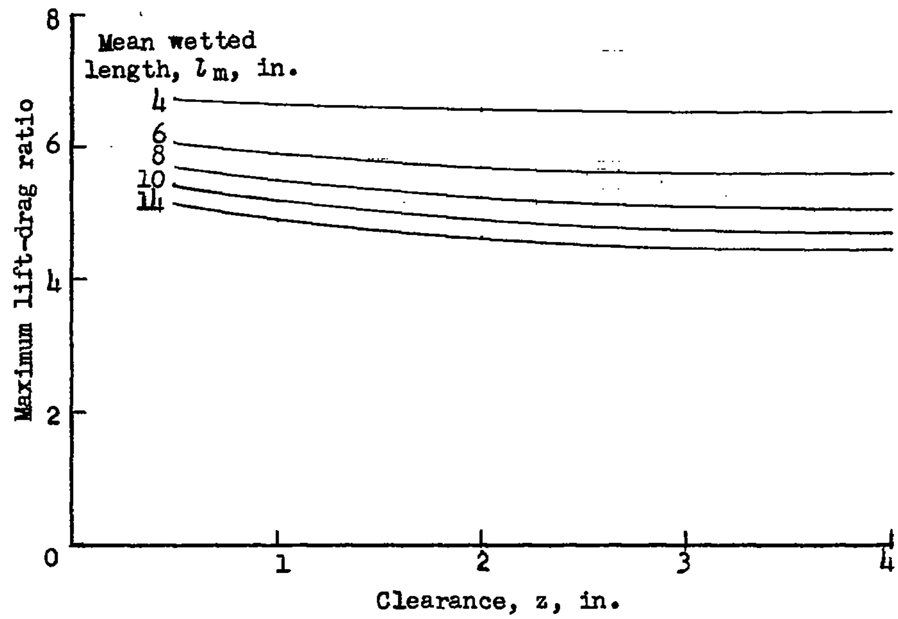


(e) Mean wetted length
l_m = 10 inches
(l_m/b = 4.0).

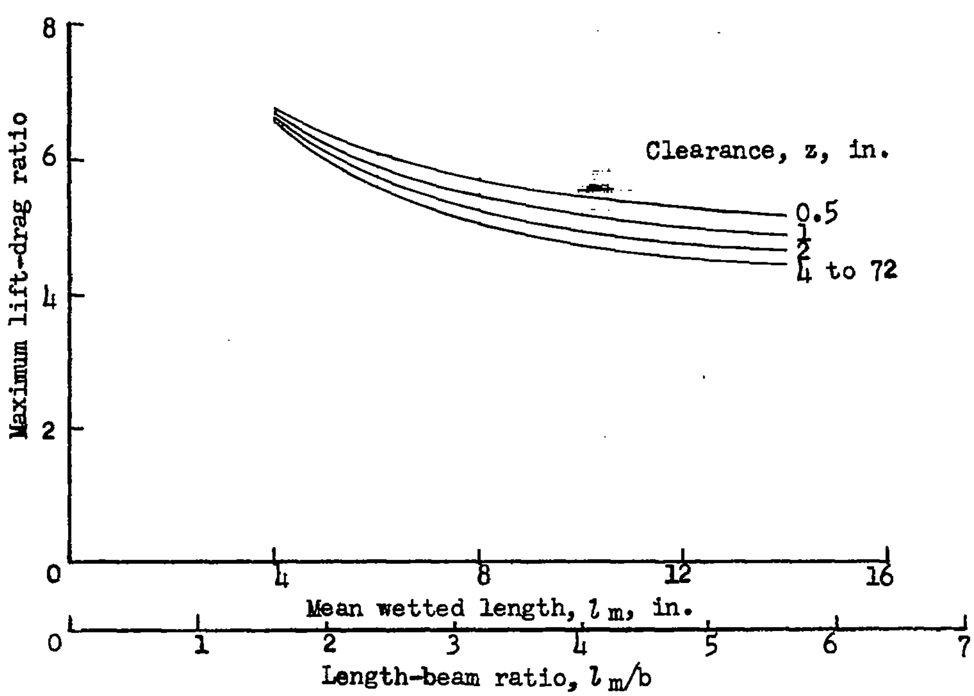


(f) Mean wetted length
l_m = 14 inches
(l_m/b = 5.6).

Figure 9.- Variation of lift-drag ratio with trim at various clearances and wetted lengths.

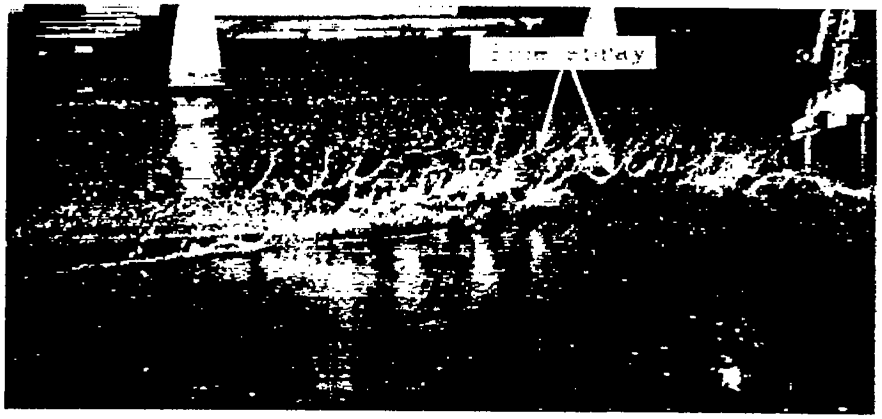


(a) Variation with clearance.



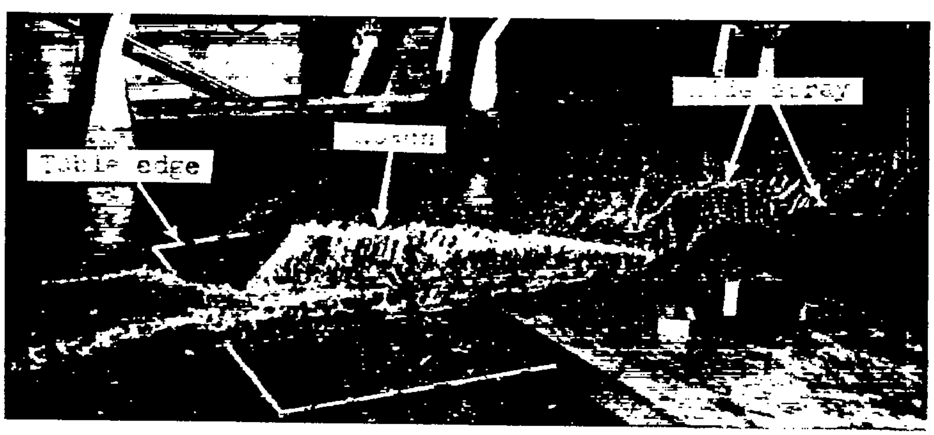
(b) Variation with wetted length.

Figure 10.- Variation of maximum lift-drag ratio with clearance and wetted length.



(a) Wake in deep water.

(b) Shallow-water roach forming.



(c) Shallow-water roach further developed.

L-91762

Figure 11.- Effect of shallow water on the roach in the wake of the model. Wetted length, 10 inches; trim, 12°; clearance, 0.5 inch.

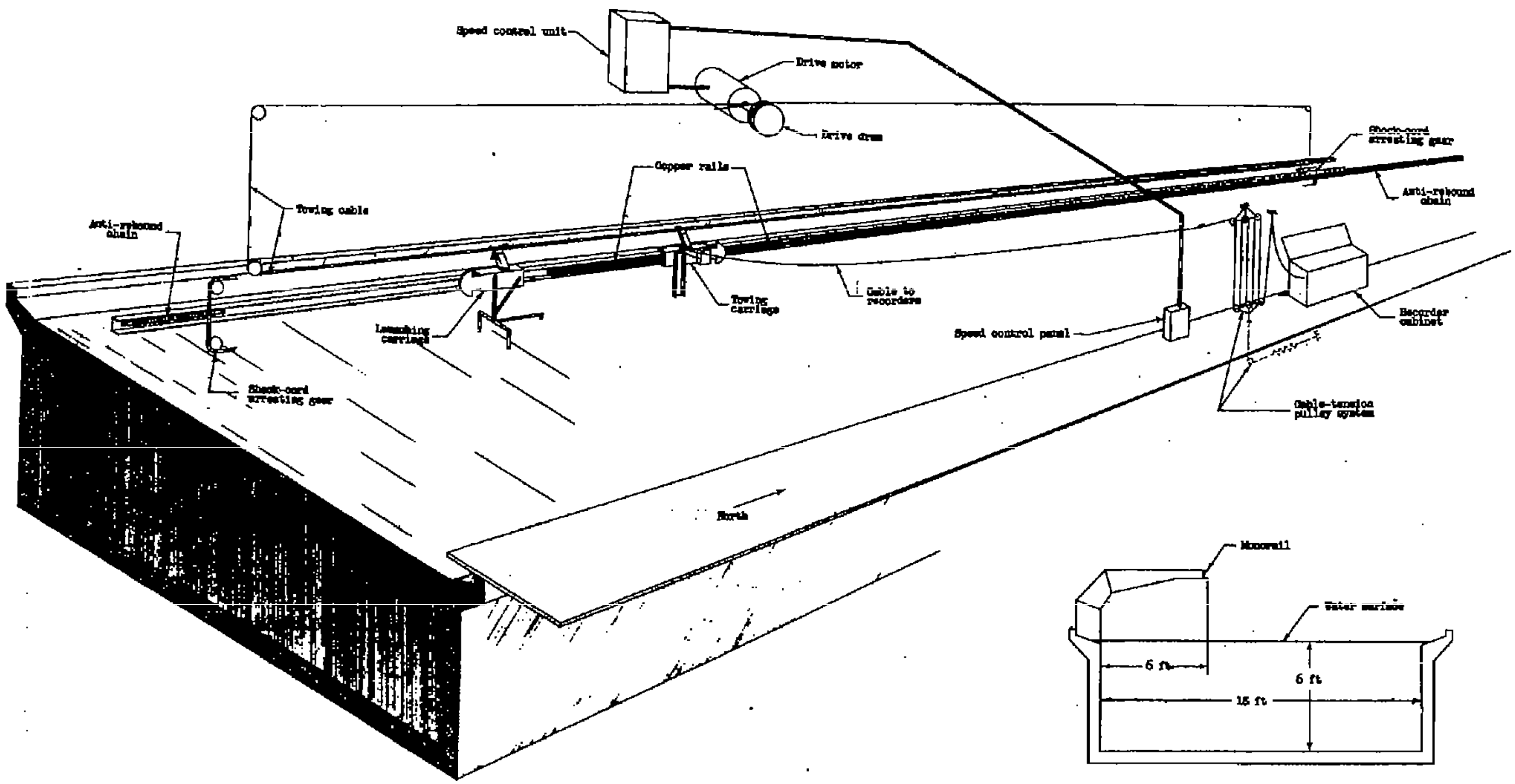
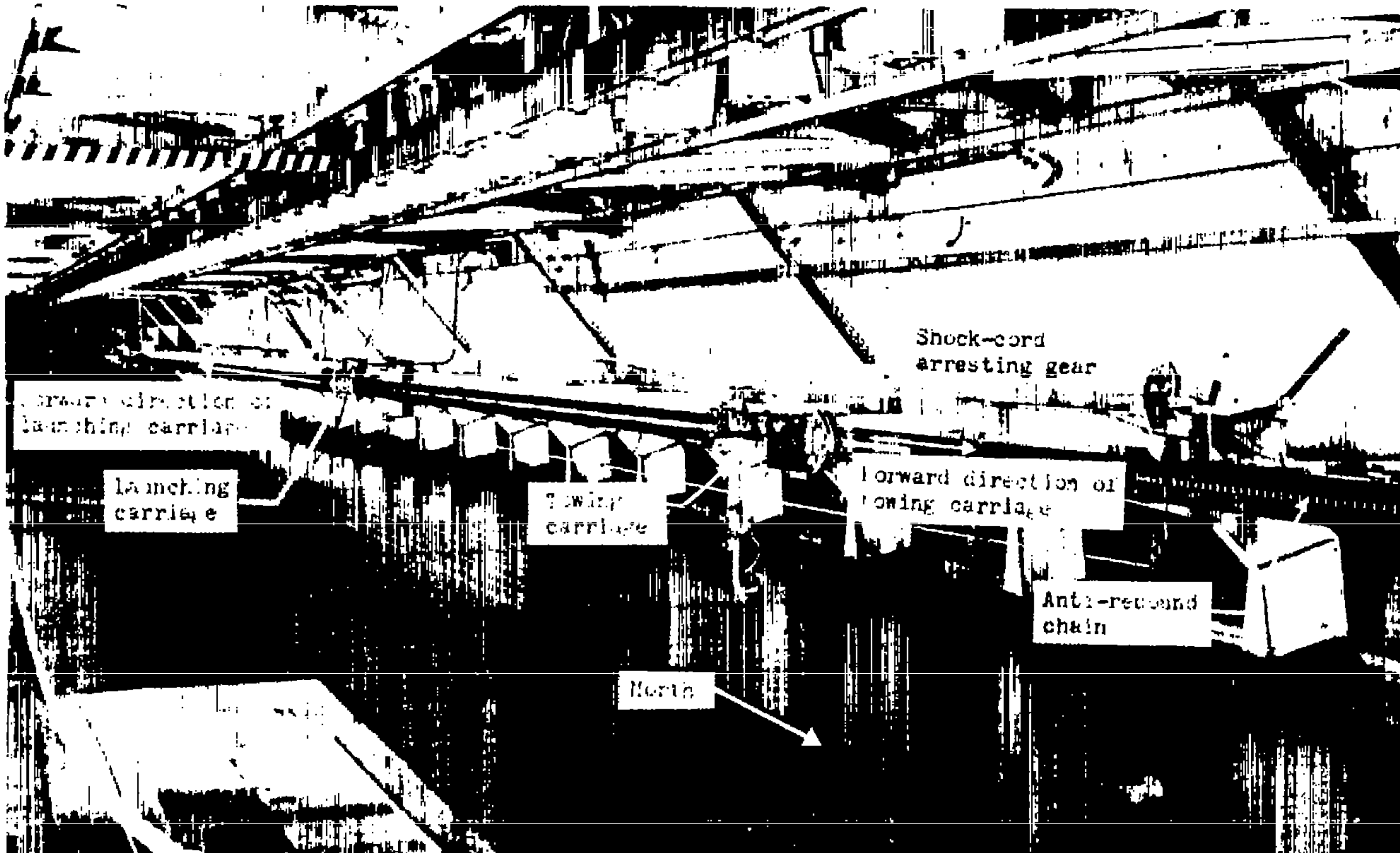
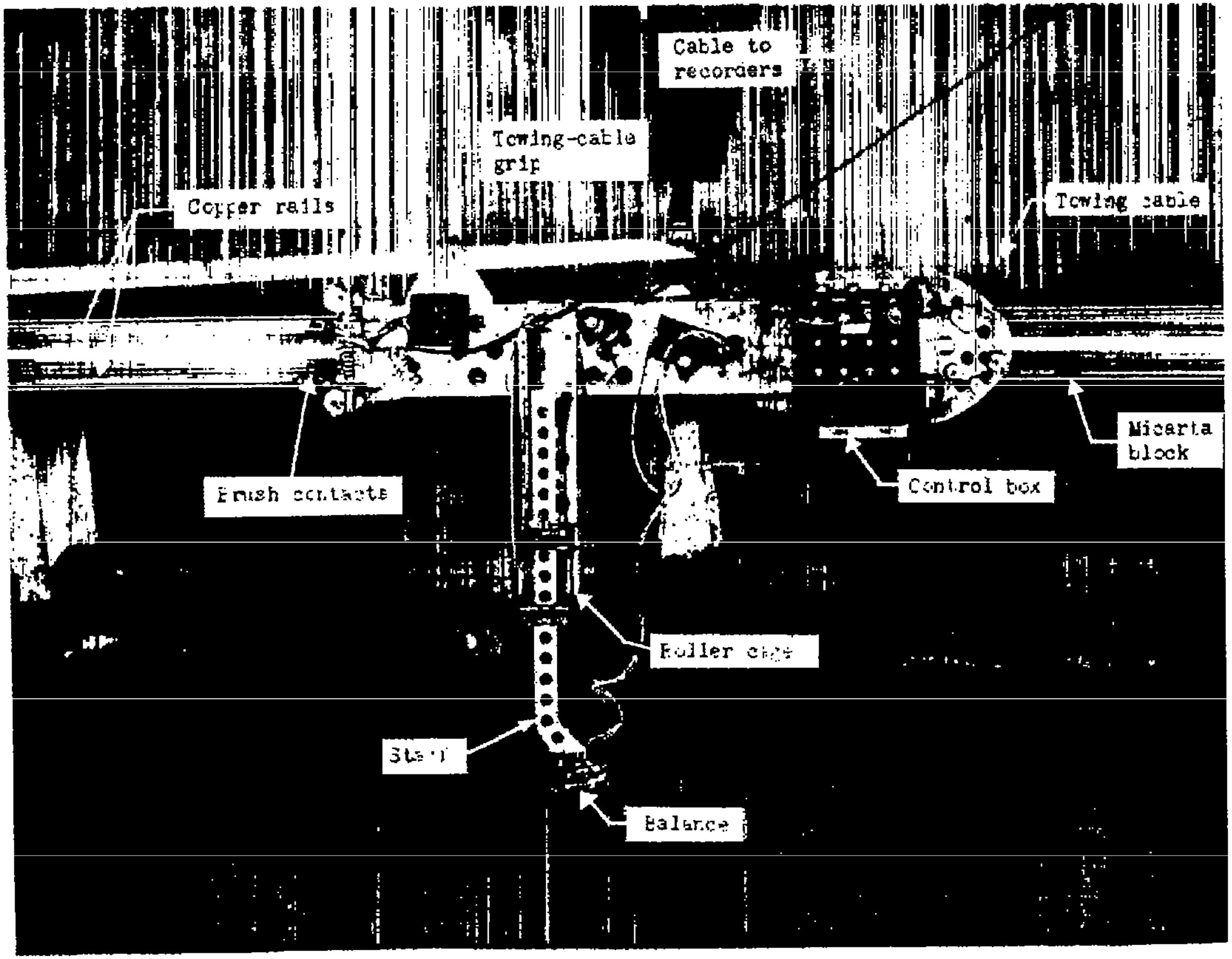


Figure 12.- Schematic sketch of monorail system.



L-87629.1

Figure 13.- General view of Langley tank no. 2 monorail.



L-87631.1

Figure 14.- Photograph of towing carriage and balance.

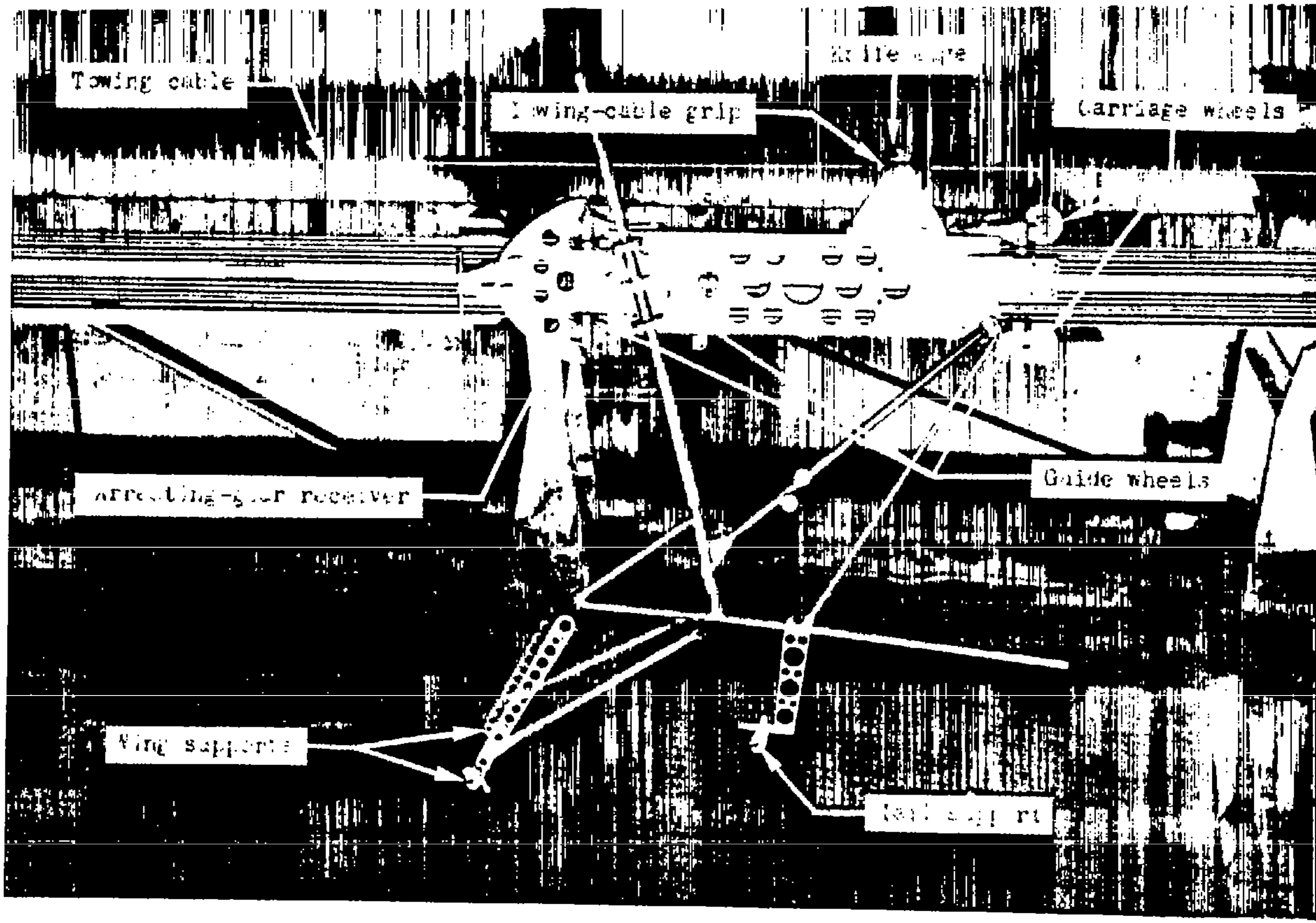
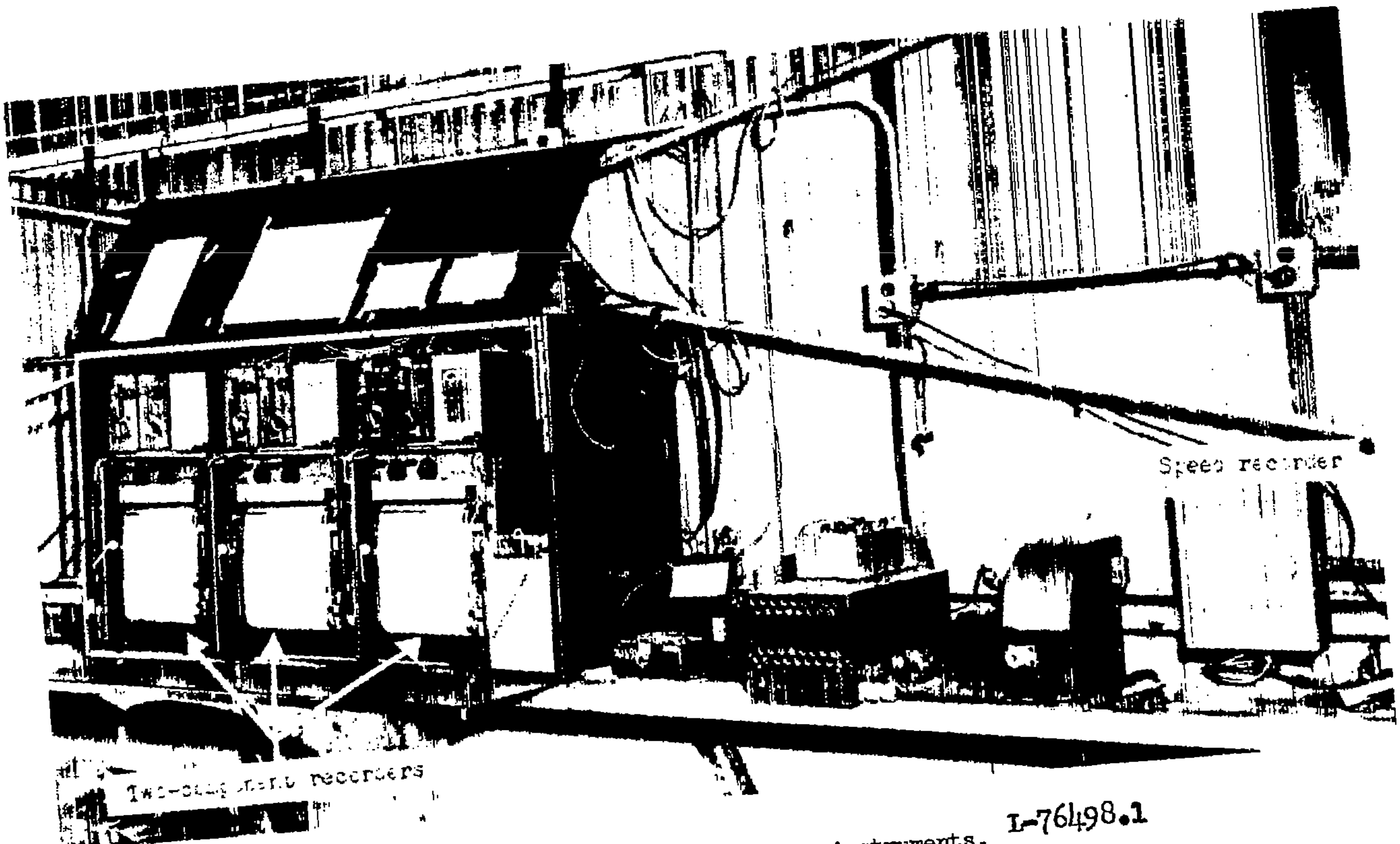


Figure 15.- Photograph of launching carriage. L-89558.1



L-76498.1

Figure 16. Photograph of recording instruments.